THE COUPLING OF PRODUCT ARCHITECTURE AND ORGANIZATIONAL STRUCTURE DECISIONS

by

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ABSTRACT

This work is motivated by our informal observation that corporations re-design their products and their organizations quite separately. We find, however, that the relationship of product architecture to organizational design is an intricate one. This study provides a rudimentary basis for understanding the linkages between product architecture and organizational design, which may allow managers to implement the appropriate organizational or architectural structures. In addition, a thorough understanding of the reliance that product architecture has upon organizational design and vice versa can aid managers in creating an environment in which product architecture can exploit the advantages of the current organizational design and in which the organizational design can enhance the efficiency of the personnel interactions required to implement a product's architecture. We discuss several observations about the dimensions by which these attributes are coupled.

Thesis Supervisor: Steven D. Eppinger
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Dedication

I dedicate this thesis to my mother and father for their innumerable sacrifices and many years of hard work that formed the foundation on which I am able to build my future.

Coming to MIT has changed my life forever. I had never imagined completing two Master's Degrees from one of the finest institutions in the world. It has been an opportunity for which I am grateful. Many people have helped me on my road to graduation, and although I'd like to acknowledge each of them personally, I am unable to do so in one page.

First, thanks to Mom, Dad, Steve, and Uncle Amrit. I would never have made it through without all of your help. Second, thanks to my wonderful friends at MIT for listening and providing invaluable advice. You (esp. Valarie, Andrew^2, and Kath) made my time here very enjoyable! Third, thanks to Ed for your unconditional support and faith in my abilities. Fourth, thanks to Lori, Romel, and Michelle for encouraging me to apply to graduate school. Fifth, thanks to my advisor, Steve, for your patient guidance and direction in completing this thesis. And, last, but not least, thanks to my typist, Andrea, for your late nights and conscientious attention to detail.

To my family and friends, with love.

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Chapter 1
Introduction

I have never let my schooling interfere with my education.
-Mark Twain

This paper explores the interdependence between two key decision areas in the development of new products: product architecture and organizational design. We conducted a field study of audio system development in a major American automotive firm. This firm competes in global markets and utilizes new technologies which give rise to several possible product architectures and organizational structures. By separating these decisions for our discussion, we are able to explore some of the fundamental issues which couple them. Our results suggest several ways in which decisions and plans for product architecture and organizational design must be integrated.

In order to explore the coupling between these two issues, we focused our study along the following dimensions: product and problem decompositions, integration mechanisms, communication patterns, supplier relationships, and reporting structures. We define product and problem decomposition to be the practice of splitting a complex engineering challenge into several simpler ones, while integration is the challenge of merging solutions to these separate problems into an overall system. Communication patterns (i.e. how information might flow) depend on the type and structure of the project team [Barczak and Wilemon 1991]. Supplier relationships can take a myriad of forms. Therefore, we were particularly interested in investigating the characteristics of these alliances which might have influenced product architectures. Reporting structures we examined were those which affected or were affected by the outcomes of the product architecture/organizational design coupling.

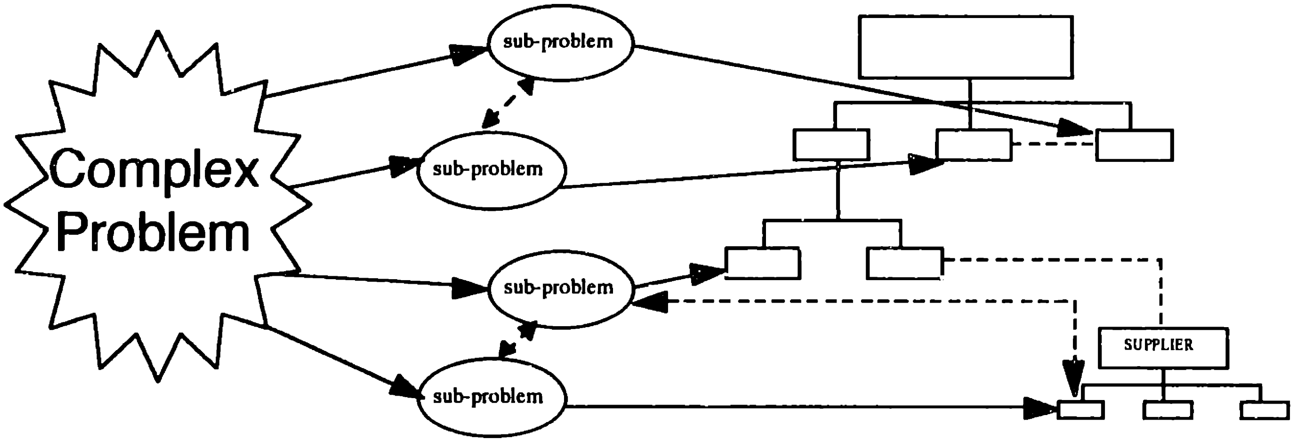

Figure 1. Problem Decomposition and Organizational Assignment
The organization must decompose the complex problem and allocate tasks to the product development team (solid arrows). Additionally, information must be coordinated across individuals, teams, and suppliers (dashed arrows).

Past research in product development has shown that a company's capability to conceive and design a variety of superior products and bring them to market faster than its competitors can be a source of significant competitive advantage [Wheelwright and Clark 1992]. Wheelwright and Clark emphasize the importance of learning in the organization. Companies that follow a path of continuous improvement in product and process development will more consistently "design it right the first time" and yield a head start in getting their products to market. An understanding of the key relationships in product planning can facilitate "design[ing] it right the first time." Prior research by Clark and Fujimoto [1991] explores the impact of strategy, organization, and management upon product development. They claim that management direction and the development organization both play critical roles in providing the integrated effort and leadership needed to successfully execute a product's architectural plan and to move that product efficiently and quickly to market. Rosenthal [1991] suggests that, in order to be successful, a firm must implement a managerial view of the design and development process that attempts to help catch design flaws early, correct mistakes, and avoid long development delays. Henderson and Clark [1990] indicate that "architectural innovation has the potential to offer firms the opportunity to gain significant advantage," in the context of understanding that a well-entrenched organization's problem solving culture can be a hindrance to architectural innovation. Finally, Clark [1987] indicates that a corporation's problem solving structure mirrors the technical and conceptual structure of its product(s). Innovative changes in the product can expose discontinuities in organizational knowledge, information flows, and procedures. Ultimately, the nature of these breaks can determine the style of competitive response [Clark 1987].

This research connects architectural choices and organizational choices. It expands on our previous research projects which have explored system integration in complex development environments. McCord and Eppinger [1993] highlight the importance of determining the needs for integration and coordination by studying the underlying technical structure of a project. Pimmler and Eppinger [1994] show that an understanding of the "system engineering" needs, which arise because of complex interactions between components of a design, is useful to define a product's architecture and to organize development teams. Finally, Morelli, Eppinger, and Gulati [1995] propose that for the management of product development projects, certain aspects of organizational design can be planned by anticipating the technical communication linkages required for project execution.

In a complex product, the co-dependencies between architectural and organizational choices can be important considerations when decomposing a problem. Alexander [1964] states that there is an important underlying structural correspondence between the pattern of a problem and the process of designing the problem's solution. In our case, it is feasible that the architectural or organizational decompositions depended on the numbers and distributions of their potential intermediate stable forms [1]. That is, the direction in which the organization or architecture might evolve can be significantly influenced by it's prior form. Complex systems will evolve from simple systems much more rapidly if there are stable intermediate forms than if there are not. Furthermore, the components of a technological system (such as a complex organization) will interact. Therefore, their characteristics will derive from the system [Bijker 1987]. Bijker,

[1] Intermediate forms refers to structures that the architecture or organization might have had prior to the current

Hughes, and Pinch [1987] give the example of the management structure of an electric light and power utility depending on the character of the functioning hardware or artifacts in the system. They also states that the management structure reflects the particular economic mix of artifacts in the system, and the layout of the artifact mix is analogous to the management structure. Simon [1990] argues that in nearly decomposable systems (such as these) the short-run behavior of each of the component subsystems is approximately independent of the short-run behavior of the other components. In the long run, the behavior of any one of the components depends only in an aggregate way on the behavior of the other components [Simon 1990]. In light of the fact that complex problems involve communication among many people, von Hippel [1990] proposes that firms specify tasks in order to reduce the problem-solving interdependence among them by predicting which tasks are likely to be important new information sources and which tasks affect each other.

1.1 Product Architecture

We define product architecture to be the set of technical decisions (the plan) for the layout of the product, its modules, and for the interactions between the modules. Product architecture is the scheme by which the function of a product is allocated to physical components. It can be a key driver of the performance of the manufacturing firm and relates to product change, product variety, component standardization, product performance, and product development management [Ulrich 1995]. In some companies, the product architectures of flagship products might even guide decision processes. At Sony, design is done very differently depending on the product. For the Walkman, generational changes are led by engineering, with heavy involvement from top management. In other products, marketing and sales lead certain classes of changes. In products that do not fit in either of the above two categories, the industrial design organization plays a heavy role [Sanderson 1995].

structure.

The physical elements of a product are the parts, components, and subassemblies that ultimately implement the product's functions. The *chunks* are the collections of these elements and so may implement one or a few functional elements in their entirety [Ulrich and Eppinger 1995]. A modular architecture is one in which chunks implement one or a few functional elements in their entirety, and where the interactions between the chunks are fundamental to the primary functions of the product. An example of a modular architecture is a car radio which is utilized in several different audio systems across vehicle lines and is a stand-alone product. An integral architecture is the opposite of a modular architecture. It is one in which a single chunk implements many of the functional elements, and where the interactions between the chunks are not well-defined and may be incidental to the function of the product. An example of an integral architecture is the integrated control panel developed for the 1996 Ford Taurus audio and climate control systems.

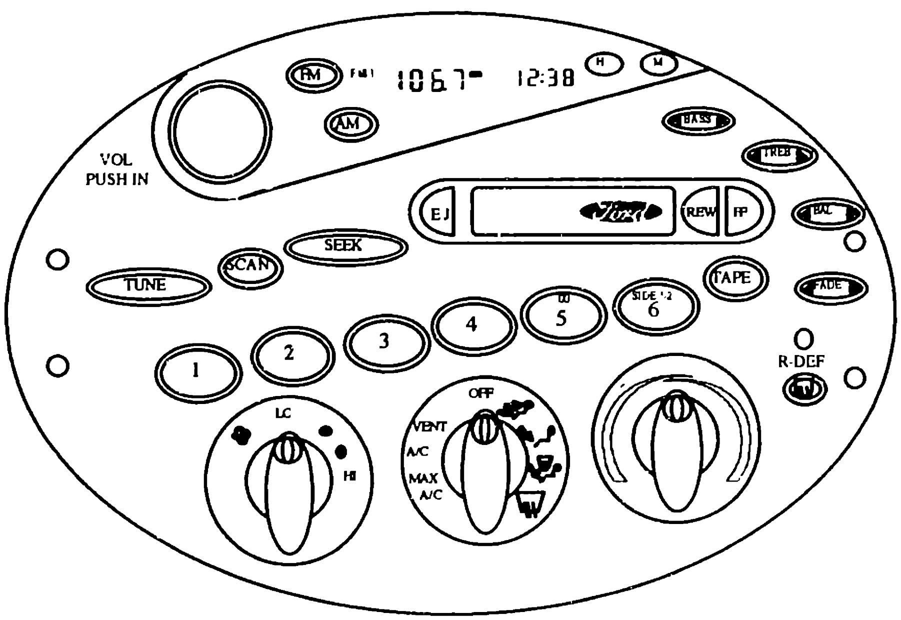

Figure 2. Ford's Integrated Control Panel

1.2 Organizational Design

Organizational design is the decision process that brings about a coherence between the goals and purposes for which the organization exists, the patterns of division of labor and interunit coordination and the people who will do the work [Galbraith 1977]. We focus our attention on the creation of formal managerial processes and communication channels that facilitate the organization's decision process. One important dimension of organizational design is the type of structure that gives rise to its capabilities and coordination abilities. A pure functional organization encourages long-term technical specialization. However, physical and organizational distance between sub-functions increases. A pure project organization focuses an organization's energies major development projects and encourages cross-functional communication. However, by doing this, it may sacrifice some functional expertise [Wheelwright and Clark 1992].

A matrix organization integrates the specialized resources of the organizations without organizing around a self-contained product or project [Galbraith 1977]. Although a matrix organization solves many of the problems of pure functional and pure project organizations, it is important to recognize that it has other drawbacks which are beyond the scope of this paper (e.g. problems caused by poor relations between units) [Galbraith 1994].

Other organizational design mechanisms include the creation of slack resources (i.e. adding additional resources and reducing each individual group's required level of performance), creating self-contained tasks (i.e. assure that each group has all the resources it needs to perform its task), investing in vertical information systems (i.e. invest in mechanisms which allow the organization to process information acquired during task performance without overloading the hierarchical communication channels), or creating lateral relations (i.e. selectively employ lateral decision processes which cut across lines of authority) [Galbraith 1973].

1.3 Coupling Architecture to Organization

While other research has analyzed the dimensions of decomposition of organizations and product architectures independently [Sanderson 1995, Uzumeri 1995, Meyer 1993], this paper highlights the ways in which organizational competencies and frameworks are coupled to architectural interactions and their function in the organizational structure. We draw the conclusion that this distinct relationship merits special consideration in managerial decision making. A thorough understanding of the reliance that product architecture has upon organizational design and vice versa can aid managers in creating a beneficial environment in which product architecture can exploit the advantages of the current organizational design and in which the organizational design can enhance the efficiency of the personnel interactions required to implement a product's architecture. Additionally, organizational design can assist the execution of a product's technology by facilitating the integration of various disciplines, technologies, components, and systems into a product.

The next section of this paper outlines our research methodology and introduces the audio-system design focus of our field work. Then we present examples of architecture affecting organizational design and organizational design affecting architecture, and discuss the coupling of these decisions. We conclude with a summary of the implications for practitioners and directions for future research.

Chapter 2
Audio System Case Studies

The data for this case study come from interviews and observations of audio system development teams in two very different organizations (one American and one European) in a major US automotive manufacturing firm. Although under the same parent company, the two sites are different in many ways, including culture, language, work habits, vehicle programs, management style, technical capabilities, supplier relationships, and scope of technical responsibility. We interviewed personnel in engineering, managerial, and business functions from global development teams on 26 different car lines and 63 audio systems. This particular company designs and manufactures about 300 different radios. The interviews were conducted over a five month period in 1995. Our study concentrated largely on factory-installed automotive audio systems. Finally, we extracted the examples from the case studies and re-framed them into more general issues for our presentation here.

An audio system consists of all the components in a vehicle which aid in providing audible information. These components include, but are not limited to the radio, amplifier, speakers, wiring harness, and cellular telephone.

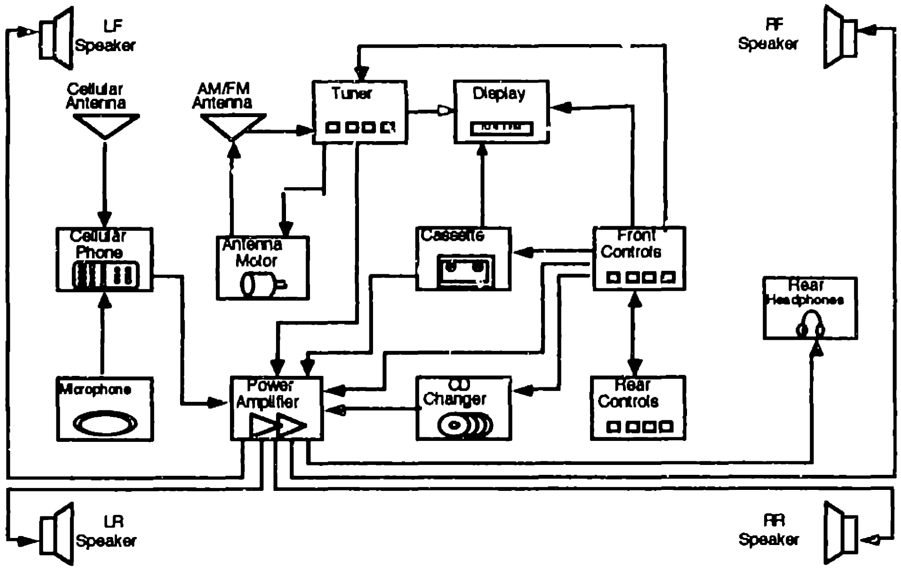

Figure 3. Audio System Architecture

At first glance, an audio system may appear to be a very simple group of components. In reality, however, it is quite complicated. An audio system can involve anywhere from 400 to 600 components, six to ten design engineers, and three to five outside suppliers. It can also take three years to fully develop. The company we studied develops ten to twenty audio systems at one time. Outside suppliers are often involved in various functions including: integrated circuit design, bezel design, lamps for displays, and telephone systems.

Some of the complexity in an audio system arises from the technical interactions and coupling effects from nesting. Nesting refers to the idea that components within a larger system are self-contained, such as the audio system within a vehicle [Christensen and Rosenbloom 1995]. Both modular and integral architectures can be arranged in a nested fashion. In a nested hierarchy, each component can also be viewed as a system which comprises sub-components whose relationships to each other are also defined by a product architecture. Similarly, the product may also be viewed as a component within a larger system, relating to other components within a defined architecture. Simply, products which at one level can be viewed as complex architected systems act as components in systems at a higher level [Christensen and Rosenbloom 1995]. Subsystems are defined as systems-of-use within a nested hierarchy of product architectures. Figure 4 illustrates a nested hierarchy of product architectures from vehicle audio systems to entire vehicle lines.

At the highest level, the architecture of a vehicle platform is comprised of all of the different vehicle lines that this particular company makes. At the vehicle platform level, pricing is determined, manufacturing issues are dealt with, modular components are specified, and the service and repair requirements are laid out. The next level down, the architecture of a vehicle line is where liaisons can be created with marketing and sales, ergonomics are taken into consideration, and noise, vibration, and harshness issues are often uncovered. At the third level, the audio subsystem level, or any other electronic subsystem for that matter, the audio-specific customer requirements are uncovered. The interface specifications and requirements and the subsystem design specifications are delineated. Lastly, the architecture of the radio, in turn, can itself be analyzed as a system composed of integrated circuits, speakers, and fascia design, for example.

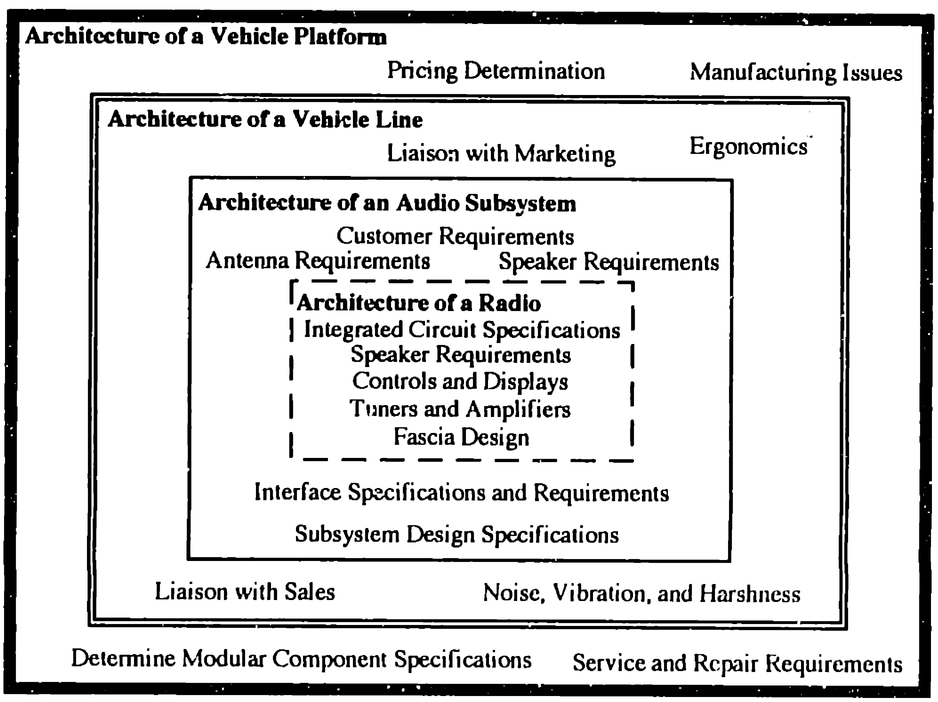

Figure 4. A nested hierarchy of product architectures

The interactions along with the nesting of the audio system in the automobile force a coupling between the audio system and the vehicle. By making design decisions of one or the other independently, a firm would sub-optimize pieces of the entire automobile.

Chapter 3
Discussion of Findings

The first problem for all of us, men and women, is not to learn, but to unlearn.
- Gloria Steinem

In this section, we will present our findings by first delineating the manner in which and to what extent architectural choices are coupled to the established organizational capabilities and structures. Next, we investigate the nature of the cases in which organizational design drove architectural decisions.

3.1 Architecture choices dictate organizational design choices.

Developing audio systems for automobiles is a surprisingly complex task. Not only is the architectural layout of a single audio system extremely complicated, but the interactions between a vehicle and its audio system may involve large numbers of people and physical parts.

3.1.1 Decomposition determines team assignments.

Products that are decomposed into architectural chunks encourage the assignment of a team to each chunk. Products are usually decomposed until a team, individual, or supplier can be assigned responsibility for each chunk [Rechtin 1991]. Traditionally the groups of functional elements in a product have had a functional team assigned to them. An example of an effective chunk-to-team mapping is the assignment of automotive systems to departments/teams such as a climate control systems or audio systems. For static modular architectures in which the interfaces are very well understood, this approach makes sense. However, when the architecture changes or if the interface parameters are not well defined, this approach becomes less appropriate as it would require the organization to change. A change in the organization would probably be very costly for just one architectural generation.

In other design domains (e.g. software), complex systems are broken into smaller, more manageable tasks. The complex details of each of the smaller sub-systems are below the *abstraction barrier*. Often there is an agreement (or *contract*) to specify the details of the interfaces and parameters passed between the complex system and each of the sub-systems. Effectively, at each level, the architecture is the plan of all these abstractions and contracts [Moses 1995] and teams are assigned to the subsystems. See Figure 5.

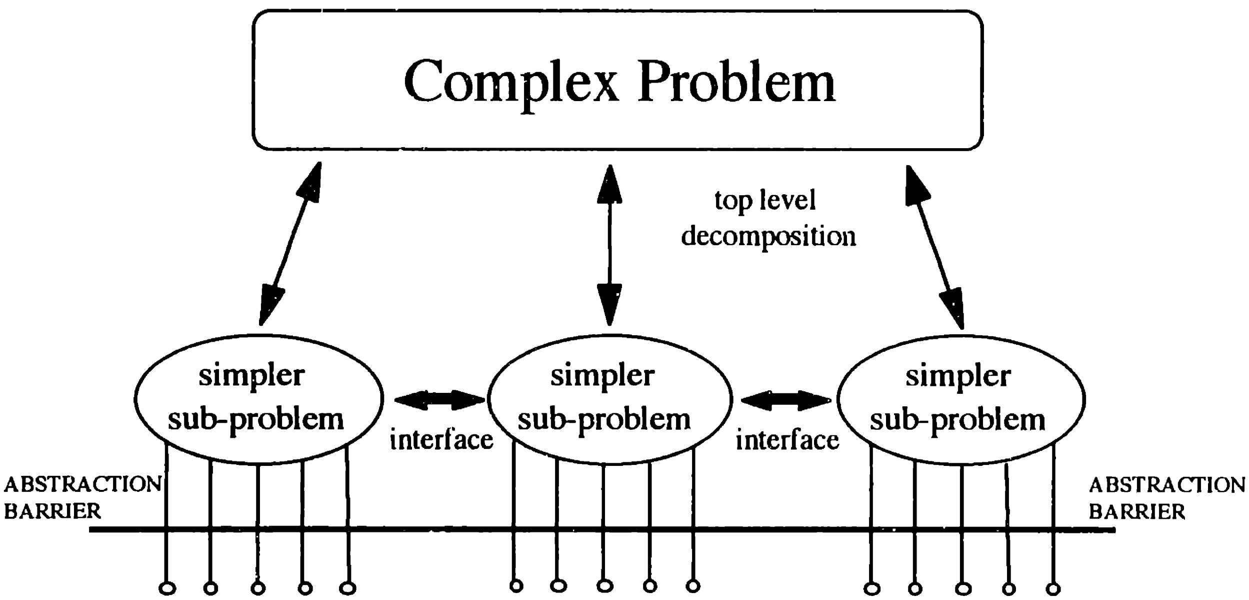

Figure 5. Problem Decomposition and Abstraction

The organization in our study traditionally has engineered strictly modular architectures. So people have been grouped not according to their technical specialties, but instead according to the physical modules of the product. Since today's audio system architectures are becoming more integrated, the organization has adapted to accommodate cross-module team structures.

3.1.2 Incidental interactions catalyze the formation of problem solving teams.

Often incidental interactions occur at the intersection of the decomposed elements. In our study, coupling problems were more difficult to anticipate in the more novel technologies. These coupling issues give rise to integration problems and cause the creation of *ad hoc* system integration teams to handle these issues. A solid analysis of where interactions can facilitate the clustering of the high frequency interactions within subsystems can minimize the interactions across difficult barriers [McCord and Eppinger 1993]. Furthermore, pre-development planning and product integrity enhance the performance of product development teams (and also minimize unplanned incidental interactions), especially if the organization is very system focused, since lead time and productivity become much more predictable [Brown and Eisenhardt 1995].

In our case study, the formation of *ad hoc* teams on a small scale was not uncommon. Though we did find that *ad hoc* teams had not been planned in advance during the product development planning process. This lack of anticipation caused the program delays and extra costs. In one instance, serious system problems had not been discovered until the entire audio system had been integrated in the vehicle during the prototyping process. Due to the urgency in correcting these issues (i.e. the vehicle could not be sold with a malfunctioning audio system and a major delay in the manufacturing of the vehicle can be extremely costly), a formal troubleshooting team was established.

3.1.3 Architecture determines communication patterns.

The layout of the product architecture's fundamental and incidental interactions implies a specific pattern of organizational communication. If there exist barriers to the execution of this pattern, these barriers can catalyze delays in the product development cycle. This issue becomes particularly relevant to co-located teams, especially if only a subset of the larger development team is being co-located. Additionally, knowledge of specific types and patterns of communication and the ability to predict communications may allow managers to implement appropriate organizational structures based on a project's task structure [Morelli, Eppinger, and Gulati 1995].

On the other hand, when one can identify that two people or two groups need to share information, it is important to assure that the correct information exchange takes place. Sometimes, an informal method such as co-location by itself is not sufficient. For example, it is important not to make the assumption that two engineers with desks in close proximity will communicate the necessary information to each other. Additionally, we know from Allen's communication vs. distance curve [Allen 1977], that it is unlikely that engineers will communicate with other engineers in their department if they are located several floors apart.

Furthermore, the availability, transfer, and use of information are all distinct concepts. Co-location increases the *availability* of the information, while *transfer* implies that the information is appropriately disseminated. *Use* implies that the actual information is utilized. Co-location does not necessarily ensure that the correct information will be transferred and used. In particular, in novel situations, where it is imperative that technical information be transmitted to a group relatively unfamiliar with the new requirements, firms might consider utilizing multiple information channels or gathering methods in order to insure transfer of the correct information and effective utilization.

3.1.4 Architecture determines the feasibility of co-location.

If a system is simple enough, the need for high-frequency interactions can be fulfilled by effectively co-locating the entire team. This approach is valid and successful for small projects and teams. When the system is complex, the same rules do not apply. If the team is large, the reasons for co-location are no longer valid. Subsystem developers do not need to interface directly with all of the vehicle developers at all times. For example, an audio system team may need to work more directly with the instrument panel design team during some part of the product development cycle; during other parts of the process the audio system design team may need to interface with the wiring harness or climate control design team. Often, there exist interactions which require technical expertise for a short time during the product development cycle.

Another way to deal with these complexities is by temporarily co-locating one or two key engineers from the subsystem development team on the vehicle engineering team. This approach might be a feasible solution if only one vehicle team existed. However, in reality each of the many vehicle teams needs the expertise of a subsystems engineer. In addition, the subsystems department itself may have its own needs and be unwilling to part with its engineer(s) for an extended period of time.

Given that multiple types of integration exist (within product development teams, within system teams which are made up of several product development teams, and between external teams and product development teams), we recognize that each integration is most difficult at the larger subsystem level [McCord and Eppinger 1993]. Additionally, past research has shown that decomposition becomes easier at the internal team level. At low levels, integration is easy because interactions occur in high frequencies over a small cross-functional team. At higher levels, interactions become more occasional and less frequent as the team gets bigger.

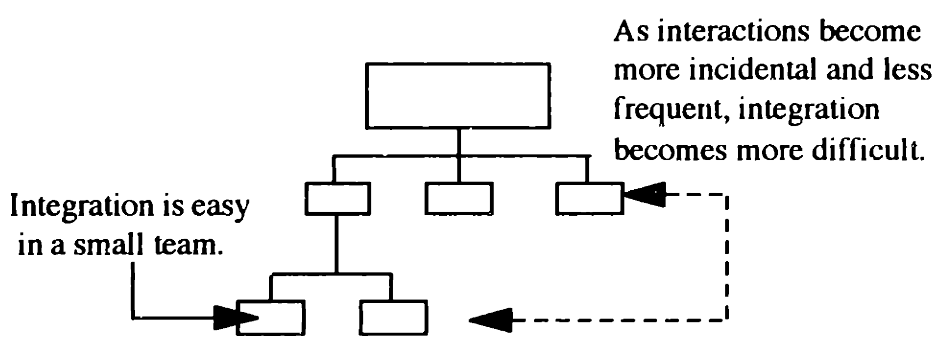

Figure 6. Interactions in an Organization

Lastly, a well understood interface between architectural chunks minimizes the need for *ad hoc* communications. If the architecture can be pre-planned and all the interfaces can be pre-specified, co-location may not be necessary. Furthermore, if complexity is accurately defined, tradeoffs between complexity, quality, and product differentiation can be thoroughly considered. In our study, one team dedicated to reducing complexity championed the complexity issue without due regard to other factors, causing many decisions to be re-examined and resulting in delays in the product development cycle.

3.2 The established organizational capabilities and structures dictate architectural choices.

The organizations that manufacture complex products such as automobiles exhibit complexity in many facets. Each division, each department, each product development team consists of many different internal and external networks. Each of these networks in turn helps to define the organization. The capabilities and structures of that organization then influence architectural design.

3.2.1 Static organizations give rise to static architectures.

Results from our study validated our prior observations that fixed organizational structures generate products whose architectures remain fairly rigid. We believe that this generalization may hold across some of the major organization types (i.e. pure product, pure functional or matrix), however this hypothesis remains to be tested in a future study. The architecture is often a reflection of the organization. If the organizational structure is static, the architecture is likely to be the same over many product generations. Integrating and changing the architecture also becomes difficult. The longer this cycle remains to be true, the stronger a prediction it becomes.

Given this premise, one might suppose splitting into project organizations, for example, would facilitate having each product architecture slightly different from the others, because each organization is a project team (i.e. either a matrix or a hybrid that cuts across all the traditional functions, but does not necessarily utilize cross-functional expertise). It appears that the project organization might be more adaptable to new architectures, because each project team is so separate. Innovations in one architecture may be difficult to implement in the other project team. In fact, each particular organization may be static and therefore produce a static architecture.

Additionally, pure project organizations tend to produce architectures reflective of that particular organization rather than that of the company as a whole. The products may also require engineering efforts that are duplicated in other segments of the corporation, hence becoming more costly than necessary [Galbraith 1973]. Pure functional organizations might be more dynamic than pure product organizations (because the product organizations are pooled together), but they are more likely to lose sight of the goals of each individual product's architecture. Matrix organizations can solve some of these problems, but they have other problems which are beyond the scope of this research. When considering organizational designs, it is important to recognize that there is no one best way to organize and not all the ways to organize are equally effective [Galbraith 1977].

3.2.2 Organizational skills and capabilities affect architecture.

An organization with specific skills sometimes chooses its architecture such that the impact of those skills are maximized in order to gain a competitive advantage. As Meyer and Utterback [1993] have shown, product families can be a result of the underlying core capabilities of the organization. Furthermore, the cross-functional skills of a successful product development organization and effective synergies with the firm's existing competencies can lead to a product advantage [Brown and Eisenhardt 1995].

For some corporations, this method has proven to be quite effective. For example, in 1933 Toyota's founder, Toyoda Kiichiroo announced, "We shall learn production techniques from the American method of mass production. But we will not copy it as it is. We shall use our own research and creativity to develop a production method that suits our own country's situation"

[Ohno 1988]. During the 1970s and 1980s, Toyota challenged GM for the title of the world's largest automobile manufacturer [Pine 1993].

3.2.3 Supplier relationships can affect architecture.

Managing supplier-customer relationships is a very complex task. Ignoring the interdependencies in this partnership can have dire consequences later in the product development cycle [Kim 1993]. Some of the major ways in which automotive suppliers have been organized in the past have been either to be dedicated suppliers or if they weren't dedicated suppliers, long term relationships had been established such that both the supplier and the manufacturer understood one another's mode of operation and the manufacturer had the ability then to anticipate and know which supplier to call when the time for early supplier involvement came around. The advantage of such a relationship is that purchasing did not have to be involved to qualify a new supplier and time was saved during the product development cycle.

In our study, the suppliers were not dedicated, and we noticed that if the suppliers did not have the same incentives as the product development teams, the quality and the timeliness of the interdependent tasks was poor. We surmise that this may be the case because each of the subteams of the larger product development team has its own organizational allegiances or personal agendas that precede their commitments to the goals of the project. Furthermore, these allegiances may exacerbate the problem of sub-optimizing the smaller systems by creating disincentives to globally optimize. In the case of the suppliers, they wanted to maximize their profits.

Sometimes, this can result in higher than necessary overall vehicle costs if the supplier develops an architecture that reaches beyond the specifications of the original architecture. An understanding of the supplier's agenda can allow one to position the product such that the supplier can either get more sales volume or utilize their engineering expertise in other profit making ventures. Lack of commitment and/or lack of goal alignment from all segments of the product development team can be due to a desire to appease upper management outside the subsystem group at the expense of a product's design, a desire for a vehicle program manager to make a radical change late in the subsystem development cycle, cultural differences in geographically disparate departments, different compensation systems in different countries, or different employee motivators in different cultures.

3.2.4 Organizational design of a globally distributed team affects architecture. Sometimes there are compelling reasons to globally distribute a multi-national product organization with global sales (e.g. keeping in touch with customers, being close to manufacturing facilities, etc.). Given this global distribution, it would be ideal to cluster the architecture such that the high-frequency interactions take place within each site and low-frequency interactions can occur across sites. We have yet to demonstrate that virtual co-location (using collaborative technologies such as video conferencing, electronic mail, distributed databases, Internet, CAE, etc.) is comparable to physical co-location.

For example, we observed that a globally distributed organizational structure can cause difficulty in scheduling video-conference or tele-conference meetings due to very little overlap in the workday and difficulty in coordinating team projects when the team itself is geographically separated. Co-location is not always the correct answer to these problems. Good reasons for co-location in a large team include situations where there is a lot of high-frequency communication, situations where interface specifications are not fully specified, or situations where communication needs are unpredictable.

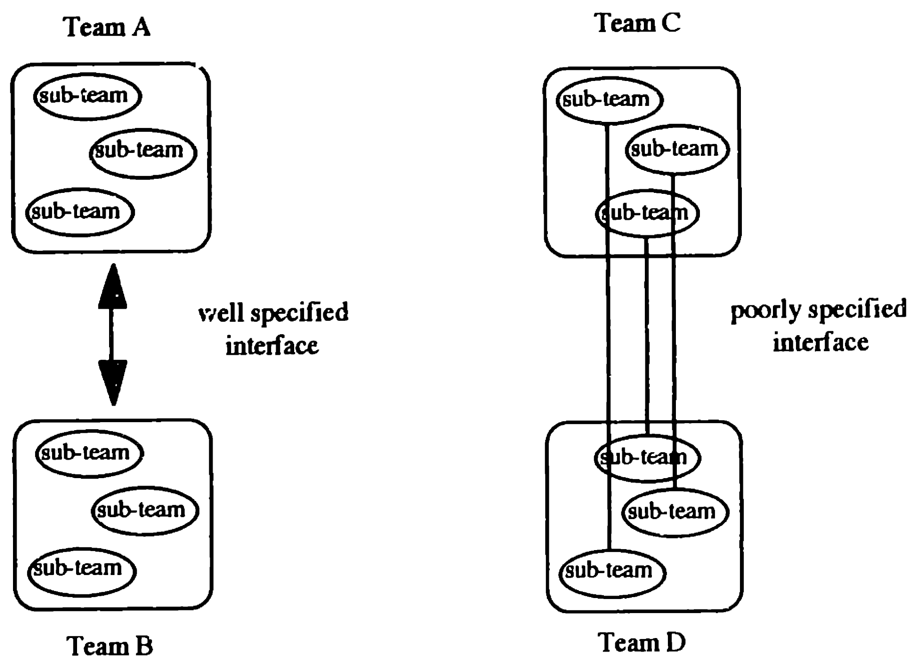

Figure 7. Co-location and High-Frequency Interactions
A well specified interface between Teams A and B allows for less formal co-location methods. However, co-locating Teams C and D would facilitate the high-frequency interactions.

Virtual co-location can ease the problem, but not alleviate it fully. Although some research [Hameri and Nihtila 1995] indicates that the use of electronic communication reduces the effect of physical distance on communication activities, face to face communication is still necessary.

The use of information technologies can be enhanced if they are seen as a tool to facilitate the business and integrated into the business. Davidow and Malone [1992] recognize that, "in years to come, incremental differences in companies' abilities to acquire, distribute, store, analyze, and invoke actions based on information will determine the winners and losers in the battle for customers." Goldman [1995] affirms this research by indicating that, "sharing the expense of precompetitive technology, facilities, and resources leaves more resources to spend on customizing product features and services that provide for competitive advantage. The goal is to unite complementary core competencies in order to serve customers whom the separate companies could not serve on their own. Each member of this type of virtual organization is chosen because it brings something unique that is needed to meet a customer opportunity."

In theory, the virtual organization can give a company access to more specialized competencies than any one organization can afford to maintain and hence concurrently engineer many more products. However, more compelling studies about the effectiveness of virtual co-location in isolation have yet to be completed.

In our study, one of the vehicle programs utilized resources from North America as well as Europe. The satellite organization did not always have access to all of the resources of the home organization to complete their projects. If this is the case, the situation is easily rectified if the home organization can insure that its satellite organizations are assigned independently executable projects. However, there must be adequate information flow between the parent organization and the satellite in order to utilize each organization's resources effectively.

Lastly, co-location should not be considered the complete solution to this problem. Tyre and von Hippel [1995] suggest that the location itself plays an integral role in a project team's efficacy. They believe that managers should consider what types of knowledge and what forms of search are most important to a team's progress at any given time, and select the work location accordingly.

3.2.5 Importance of effective communication

Automotive audio systems have traditionally been designed by largely autonomous organizations either within automobile manufacturing firms or at supplier firms. Sometimes this type of organizational structure promotes the visual style of an audio system interface to be very different from the style of the vehicle itself. Recognizing this problem, the US auto industry has placed greater emphasis on organizing vehicle line teams. In this fashion, they hope to create natural communication patterns between subsystem designers (e.g., audio systems) and the vehicle interior designers.

Organizations tend to develop languages of their own as people who share a common set of problems tend to share shorthand ways of referring to activities and technologies. Technical departments hire people who have been trained and know the language of the department's specialty. Such a language permits people to communicate more efficiently by transmitting more information with fewer symbols. However, despite the fact that specialized languages increase efficiency within a department, they decrease efficiency between organizations [Galbraith 1973].

Many of the interactions we studied involved these types of formal organizational ties. However, we did observe that much of the necessary technical communication occurred through the informal organizational networks. Krackhardt and Hanson [1993] indicate that although these informal networks can expedite delayed initiatives and aid in meeting difficult deadlines, they can also block communication and evoke opposition unless managers know how to identify and direct them. Moreover, Granovetter's [1973] research has shown that small-scale interactions can be translated into large-scale patterns, that is the strength of interpersonal ties can affect the political makeup of the organization.

3.2.6 The underlying philosophies of an international corporation often assume global ease of communication.

Architectural direction can be very difficult to communicate across organizations. For example, even the simplest explanations of architectural characteristics can be misinterpreted if a group speaking American English conveys the message to a group speaking British English or a group speaking English translated from German.

In the company that we studied, the European division and the North American division shared only human capital until recently, now they also share products. Only now is this company experiencing the growing pains of globalization as heightened by the differences in each organization's decision models and understandings of organizational processes.

As Allison [1971] showed through his analysis of the Cuban missile crisis, the acts of complex organizations cannot be simply understood by analogy as the purposive acts of individuals. This simplification obscures the neglected fact that corporate policy decisions are not made by one decisionmaker, but rather by the bureaucratic results of a conglomerate of large internal organizations.

Social research has shown that the creation of lateral relations in an organization often provides a mechanism which reduces the quantity of decisions referred upward in the corporate hierarchy. It is assumed that informal processes are necessary and inevitable in a complex organization. However, when a large product development team is comprised of differing attitudes, contains members from different countries and is geographically dispersed, the effective use of joint decision making may also require a formally designed process [Galbraith 1973].

Identification of internally efficient departments which are hindered by barriers to external communication may allow an organization to select a product architecture such that the high-frequency interactions occur *inside* departments rather than *across* departments.

3.2.7 Effects of organizational culture on architecture.

Organizations as a whole show patterns of basic assumptions that are invented, discovered, or developed by given groups as they learn to cope with their specific problems. These problems include, but are not limited to external adaptation and internal integration [Schein 1985]. Groups within the organization may also exhibit their own distinct *group culture*.

We observed that the shared experiences, knowledge, and understanding of the organization caused each group to bring different assumptions with it to the larger product development team and as a result affected architecture decisions.

In one example, the company wanted to design a single audio architecture for global use. However, engineering decisions regarding interfaces and connections became very difficult to resolve. We later found that the European engineers regard modularity (and upgradability) as fundamental to a product's architecture, whereas the North American engineers focus more on specific product and vehicle line features. Interestingly enough, this finding reflects not only a difference in organizational cultures, but appears to suggest that this difference is due to distinct differences in the regional customers. This difference may affect the firm's ability to manage the discontinuity between present products and unknown future products and hamper a thorough understanding of their markets and customers [Dougherty 1987].

The managerial implications of understanding a group's culture include enhancing management's ability to utilize tacit, highly situated knowledge of employees such as machine operators, secretaries, or customers [Tyre and von Hippel 1995]. Tyre and von Hippel [1995] suggest that observing these kinds of employees in their normal work environment (i.e. their sub-group culture or shared values) allows managers to develop a "contextualized appreciation" of issues that these employees may face.

Lastly, Foster [1986] has shown that technological change necessitates significant organizational change. He states that companies lose their leadership not only because of weak strategies, but also because of strong cultures.

Chapter 4
Future Research Directions

While we were able to make string observations based on our field study, many of our conclusions are merely speculative since this study represents only a single class of product design. In order to strengthen the conclusions that might be drawn, it would be useful to conduct studies of several different products to confirm the robustness of our findings. Additionally, an exploration of the following research questions might also be informative: How can the time constants for organizational change and for architectural change be measured? When is the time constant for the organizational change smaller than the time constant for architectural change? What attributes of product plans and organizational design plans lend themselves to enhancing strategic planning? What types of organizations can more easily adopt new product architectures? Is an organization where the major skills and capabilities of the people set the parameters of the product architectures more successful than one in which the product architectures dictate the organizational structure? Can requirements for high-frequency and low-frequency communications be identified by a priori knowledge of interface specifications? To what extent do collaboration technologies change the nature of technical interactions in product development?

Chapter 5
Corporate Policy Implications of this Research

The framework proposed in this thesis highlights the co-evolution of product architecture and organizational design. Results from this study may be particularly relevant to co-located product development teams, large companies that develop complex electro-mechanical products, or any large, geographically dispersed organization desiring to execute a complex task. In addition, these results can enhance an understanding of the capabilities of virtual co-location. This research can improve a manager's ability to organize and co-locate large and complex development projects, resulting in a more effective utilization of resources, reduced complexity or personnel interactions, shorter development times, and reduced project costs.

A second way in which corporate management can apply this research is in determining a *firm's value network* (the context within which a firm competes and solves customers' problems) [Christensen and Rosenbloom 1995]. Christensen and Rosenbloom's research shows that companies which developed and adopted technologies which addressed user needs in different, emerging value networks disrupted "established trajectories" of technological process in established markets. We propose that a solid understanding of the role of product architecture and organizational design in adopting new technologies can be an important factor in affecting whether incumbent or entrant firms will successfully innovate in new technologies.

A third key use of this research is related to companies' increasing tendencies towards *mass customization.* Mass customization makes the identification and fulfillment of the wants and needs of individual customers paramount without sacrificing efficiency, effectiveness, and low costs [Pine 1993]. It can be a viable and important strategy in architecture decisions, in that it might create new decomposition patterns.

Fourth, an understanding of co-evolution, even just in the manufacturing stage of the product development cycle can be beneficial. As Goldhar [1991] points out; (1) a failure to understand fully the strategic and organizational changes accompany new technology; and (2) failure to understand the essential new role of information technology in system integration of system engineering problems can cause firms to fail to attain the expected level of benefits from their investments in flexible [manufacturing] systems technologies. Again, we feel that understanding co-evolution even just in the manufacturing stage of the product development cycle can be beneficial.

Lastly, in order for corporations to expand on the lessons learned in this study, we recommend two methodologies, the DSM (Design Structure Matrix) and systems dynamics thinking models. A DSM can help understand the specific nature of communication pairs within the organization by creating a mapping of task-based interactions between individuals or groups. This understanding can better exploit the advantages of co-location. The DSM takes a systems orientation allowing the entire system to be considered. It shows, in compact notation, the interrelationships between tasks. Marks placed in specific places in the matrix show, for each task, from which tasks inputs are received and which tasks information is supplied to. In addition, feedback loops which play a significant role in most processes, are clearly identified through the use of the matrix. Controlling the communication between the tasks in a feedback loop is vital to the timely and accurate execution of the process [Eppinger 1994]. Utilizing systems dynamics computer models can aid in identifying five different types of thinking skills: dynamic, generic, structural, operational, and scientific [Richmond 1990].

Chapter 6
Conclusion

... Never ending, still beginning,...
- John Dryden

This paper describes our exploration of the linkages between product architecture and organizational design by bringing forth specific examples solidifying the premise that product architecture and organizational design are not independent. In fact, they are interdependent and affect each other as we have found through our case studies. For this study, we interviewed members of audio-system teams in two very different organizations of a large American automotive manufacturing firm. We found that the technical decisions relating to decomposition, architecture and integration are tightly coupled to both the capabilities and the design of the organization which must execute the development process.

We observed in our case studies that organizations do *simultaneously* exhibit mechanisms of product architecture affecting organizational structure as well as patterns of organizational structure affecting product architecture. Hence, we assert that the technical architecture of a product co-evolves with the organizational design. The notion of co-evolution is a dynamic extension of Conway's earlier observation that organizations create technical system designs which match the communications structure of the organization itself [Conway 1968].

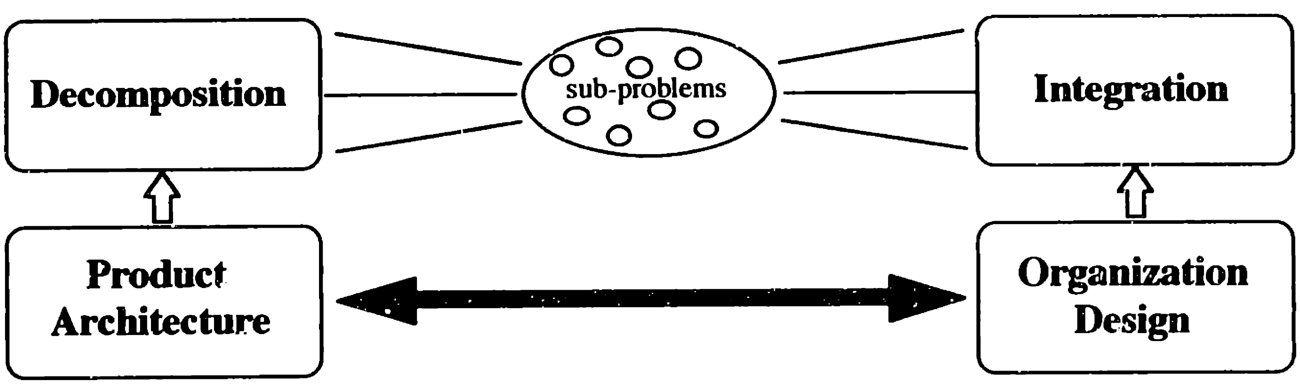

Figure 8. Problem Relationships

We propose a possible mechanism which may help to explain this fundamental coupling: architecture and organization are linked through the process of problem decomposition and system integration. Developers handle complex system design challenges by decomposing the large system into simpler ones which can then be designed or specified for outsourcing. (This decomposition process is repeated until the subsystems are simple enough to tackle.) At some point, the development organization's challenge is to integrate the various pieces together into a complete working system. In fact, decomposition and integration are generalized inverse problems.

We are of the opinion that establishing and following procedures which take advantage of the benefits achieved through recognizing the coupling of these decisions can facilitate the product development process. Inappropriate or inflexible architectural or organizational frameworks may be curtailed. For example, if an organization has evolved from being too closely aligned to a very modular product architecture, an understanding of co-evolution may catalyze a more balanced move towards a more integrated organizational structure. Perhaps a more effective matrix structure can be formed.

Over time the product architecture will change at a different rate than the design of the organization. Even though these changes happen slowly, it is essential to acknowledge the coupling at the decision level in order to achieve the benefits of recognizing their interdependence. It does not appear feasible for new generations of architectural changes to far exceed that of the pace of organizational re-structuring.

Chapter 7
Annotated Bibliography

Alexander, C. (1964). Notes on the Synthesis of Form. Cambridge, Massachusetts, Harvard University Press.

As more and more design problems reach insoluble levels of complexity, a body of information and specialist experience is growing. The quantity of information itself by now beyond the reach of single designers, and the various specialists who retail it are narrow and unfamiliar with the form-makers' peculiar problems, so that it is never quite clear how the designer should best consult them. These notes describe a way of representing design problems which does make them easier to solve. It is a way of reducing the gap between the designer's small capacity and the great size of his or her task.

Allen, T. J. (1977). Managing the Flow of Technology. Cambridge, MA, MIT Press.

This work provides an overview of the communication system in technology, presents Allen's research methods and describes differences in the career paths and goals of engineers and scientists that cause special problems for organizations. Allen also discusses how technological information is acquired by the R&D organization. He then shows how critical technical communication within the laboratory is for R&D performance, and originates the idea of "gatekeeper," the person who links his or her organization to the world at large. Allen concludes by discussing the influence of formal and informal organization and of architecture and office layouts on communication.

Allison, G. T. (1971). Essence of Decision: Explaining the Cuban Missile Crisis. Boston, Massachusetts, Little, Brown, and Company.

This book consists of three case studies, each of which uses one frame-of-reference in searching for answers to the major questions of the Cuban Missile Crisis. Central questions that Allison concentrates on are the following: (1)Why did the Soviet Union place strategic offensive missiles in Cuba; (2)Why did the United States respond with a Naval quarantine of Soviet shipments to Cuba; (3)Why were the missiles withdrawn?; (4)What are the lessons of the Missile Crisis? The three frames-of-reference that Allison uses to answer these questions are: (1)Rational Actor Or Classical Model (Model 1); (2)Organizational Process Model (Model 2); (3)Governmental (Bureaucratic) Politics Model (Model 3). Model 1 predicts what a nation will do or would have done by calculating the rational thing an individual would do in a certain situation. Model 2 identifies the important sub organizations within a large organization, and its predictions identify trends that reflect established organizations and their fixed procedures and programs. Model 3 focuses on the politics of a government. What happens is characterized as a resultant of various bargaining games among players in the national governments.

Barczak, G. and D. Wilemon (1991). "Communications Patterns of New Product Development Team Leaders." IEEE Transactions on Engineering Management **38**(No. 2).

New product development (NPD) teams can be viewed as information creating and processing systems. As such, they are dependent on effective intra-team and extra-team communication. The team leader plays an important role in this communication process by fostering communication within the team and acting as a liaison (boundary spanner) between the team and other groups (e.g., manufacturing, customers, vendors). This study focuses on two types of NPD team leaders-operating and innovating-and explores their communication patterns with team members and external groups. The results indicate that the communication patterns of NPD team leaders are dependent on the type of team. Further, the authors' findings show that degree of success differentiates the communication patterns of team leaders, particularly within operating types of teams.

Bijker, W. E., T. P. Hughes, et al. (1987). The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. Cambridge, Massachusetts, The MIT Press.

This book stemmed from a workshop of the European Association for the Study of Science and Technology. The first portion of the book aims to contribute to a greater understanding of the social processes involved in technological development. In particular, the authors define the "seamless web", i.e. that both science and technology are socially constructed cultures and that the boundary between them is a matter for social negotiation and represents no underlying distinction.

Brown, S. L. and K. M. Eisenhardt (1995). "Product Development: Past Research, Present Findings, and Future Directions." Academy of Management Review **20**(4): 343-378.

The literature of product development continues to grow. This research is varied and vibrant, yet large and fragmented. In this article, the authors first organize the burgeoning product-development literature into three streams of research: product development as rational plan, communication web, and disciplined problem solving. Second, the authors synthesize research findings into a model of factors affecting the success of product development. This model highlights the distinction between process performance and product effectiveness and the importance of agents, including team members, project leaders, senior management, customers, and suppliers, whose behavior affects these outcomes. Third, the authors indicate potential paths for future research based on the concepts and links that are missing or not well defined in the model.

Christensen, C. M. and R. S. Rosenbloom (1995). "Explaining the Attacker's Advantage: Technological Paradigms, Organizational Dynamics, and the Value Network." Research Policy(24): 233-257.

Understanding when entrants might have an advantage over an industry's incumbent firms in developing and adopting new technologies is a question which several scholars have explained in terms of technological capabilities or organizational dynamics. This paper proposes that the value network-the context within which a firm competes and solves customers' problems-is an important factor affecting whether incumbent or entrant firms most successfully innovate. In a study of technology development in the disk drive industry, the authors found that incumbents led the industry in developing and adopting new technologies of every sort identified by earlier scholars - at component and architectural levels; competency-enhancing and competency-destroying; incremental and radical-as long as the technology addressed customers' needs within the value network in which the incumbents competed. It is in these innovations, which disrupted established trajectories of technological progress in established markets, that attackers proved to have an advantage. The rate of improvement in product performance which technologists provide may exceed the rate of improvement demanded in established markets. This mismatch between trajectories enables firms entering emerging value networks subsequently to attack the industry's established markets as well.

Clark, K. B. (1987). Knowledge, Problem-Solving, and Innovation in the Evolutionary Firm: Implications for Managerial Capability and Competitive Interaction. Boston, MA, Harvard Business School Division of Research,.

The literature on competition and the management of innovation has been dominated by two themes: (1) the managerial problems associated with responding to radical innovation; and (2) the optimal strategy for committing resources to innovation. Yet empirical evidence suggests that a great deal of competitive interaction involves problems of implementing a response to products (or processes) with [apparently] modest differences in technology. Understanding why established competitors might have difficulty in there circumstances requires an understanding of the way technology and the associated managerial skills in solving problems evolve. This paper develops a framework for exploring the link between the pattern of innovation as technology evolves and the development of managerial skills in formulating and solving problems. Focusing on product development, the paper lays out the relationship between problem solving and the nature of knowledge the firm has about the design and manufacture of its product. The framework is used to develop a set of propositions about the structure of specialization and information processing. A central result is that this structure mirrors the technical and conceptual structure of the product, Innovative changes in the product are therefore likely to expose gaps in knowledge, information channels, and procedures. The nature of those gaps determines the problematic nature of competitive response.

Clark, K. B. and T. Fujimoto (1991). Product Development Performance: Strategy, Organization, and Management in the World Auto Industry. Boston, MA, Harvard Business School Press.

This book is about the development of new products in the turbulent and demanding environment of the auto industry. According to the authors, product development is driven largely by three forces that have emerged over the past two decades in many industries worldwide These three forces are intense international competition, fragmented markets and sophisticated customers and diversified and transforming technologies.

Conway, M. E. (1968). "How Do Committees Invent?" Datamation 14(4): 28-31.

The basic thesis of this article is that organizations which design systems are constrained to produce designs which are copies of the communication structures of these organizations. The article details out the stages of design, its subsystems, and then relates the two. Lastly, it draws the conclusions that systems image their design groups and lists out reasons that large systems disintegrate.

Davidow, W. H. and M. S. Malone (1992). The Virtual Corporation. New York, Harper Books.

Davidow and Malone refer to the virtual corporation in terms of patterns of information and relationships. The virtual corporation has no single identity. To the outside observer, it appears almost edgeless, with permeable and continuously changing interfaces between company, supplier, and customers. Form inside the firm the view will be no less amorphous, with traditional office, departments, and operating divisions constantly reforming according to need. Through case studies, this book shows how virtual products have affected companies across a wide spectrum of industries. In addition, they discuss how these changes relate to the vision of the virtual corporation. The goal of the book is to put forth a vision of the corporation of the twenty-first century.

Dougherty, D. (1987). "New Products in Old Organizations: The Myth of the Better Mousetrap in Search of the Beaten Path." Doctoral Dissertation, MIT Sloan School of Management. Cambridge, MA.

This research examines the process of new product development in large firms, emphasizing how it is that people comprehend "the market," or not. Eighty people from five large firms were interviewed regarding one of sixteen recent new product efforts they had participated in. The people represent the major functions of sales, marketing and planning, engineering, and manufacturing. In addition, site visits and archival analyses were carried out. All of the products have been introduced, several have since been canceled, several remain uncertain, and several appear to be successful.

Eppinger, S. D., D. E. Whitney, et al. (1994). "A Model-Based Method for Organizing Tasks in Product Development." Research in Engineering Design.

This research is aimed at structuring complex design projects in order to develop better products more quickly. The authors use a matrix representation to capture both the sequence of and the technical relationships among the many design tasks to be performed. These relationships define the "technical structure" of a project which is then analyzed in order to find alternative sequences and/or definitions of the tasks. Such improved design procedures offer opportunities to speed development progress by streamlining the inter-task coordination. After using this technique to model design processes in several organizations, the authors have developed a design management strategy which focuses attention on the essential information transfer requirements of a technical project.

Foster, R. (1986). Innovation: The Attacker's Advantage. New York, Summit.

Companies today face the difficult task of self-renewal and innovation. This book explores the difficulties in the innovation process. Foster offers a framework for deciding in which technologies to invest. In addition, Foster recognizes that people must change in order for a company to embrace a new technology.

Galbraith, J. R. (1973). Designing Complex Organizations. London, Addison-Wesley.

This book attempts to present an analytical framework of the design of organizations and particularly types of organizations which apply lateral decision processes or matrix forms. The book assumes that matrix management structures cannot encompass all scenarios which require coordination. Hence, there exist major defects in any choice an organization makes. The author assumes that if certain lateral processes do not arise spontaneously, they can be designed. The framework in the book attempts to identify the types of matrix designs and the conditions under which they are appropriate. Several cases are illustrated and analyzed.

Galbraith, J. R. (1977). Organizational Design. London, Addison-Wesley.

This book is focused on choices of organizational forms. The audience is primarily those people who will make the choices by which organizations will be designed. These people are the mangers and employees who work or will work in these social forms. The author's purpose is to present a framework to aid these people in recognizing the ways by which their organization can be designed.

Galbraith, J. R. (1994). Competing with Flexible Lateral Organizations. London, Addison-Wesley.

The lateral organization, no matter what its form, is a mechanism for decentralizing general management decisions by recreating the organization in microcosm for the issue at hand. This book is about building lateral organizational capability. The author provides an argument for using organizational capability in general, and lateral organizational capability in particular, as a competitive advantage. The main focus of the book is on creating, designing, and building the various types of lateral organizational capability.

Goldhar, J. D., M. Jelinek, et al. (1991). "Flexibility and Competitive Advantage- Manufacturing Becomes a Service Business." Int. J. Technology Management, Special Issues on Manufacturing Strategy **6**(3/4): 243-259.

Much has been reported about the seeming inability of many firms to attains the expected level of benefits from their investments in CIM and FMS technology. Some of the blame has been placed on inappropriate expectations, some on bad project management, and some on errors in the analytical methods used to evaluate and justify the investments. All of these 'errors' undoubtedly contribute to the problem; but the authors believe that two more fundamental difficulties are at issue: (1) a failure to understand fully the strategic and organizational changes that must accompany the new technology; and (2) a failure to understand the essential new role of information technology in the integration of engineering, manufacturing and marketing and in the design of flexible manufacturing systems. As yet, few managers see the relationship between flexibility on the factory floor on the one hand, and strategic flexibility in the organization, and the marketplace, on the other. Nor is such a flexibility widely enough viewed as a source of competitive advantage. This paper will briefly discuss the evolution of manufacturing technology and management to highlight how traditional constraints and relationships between manufacturing, engineering and marketing are changed by computer technology. The authors will then focus on how manufacturing operations are changed, and a new economics of production created. Finally, they will describe a new philosophy for manufacturing along with the new strategies they permit, and the organization designs and management systems that are required; and made possible, by the utilization of information technology.

Goldman, S., R. Nagel, et al. (1995). Agile Competitors and Virtual Organizations. New York, Van Nostrand Reinhold.

This book focuses on the marketing, organization, management, and human resource levels of agile competition. It identifies emerging patterns of competition and their implications for how companies and people need to change in order to be able to prosper in a new environment. Agile competition is about how more and more businesses are being run today in order to stay in business. It is characterized by customer-enriching marketing, the ability to manufacture goods and to produce services or customer orders in arbitrary lot sizes, it a holistic design methodology that integrates supplier relations, production process, business processes, customer relations, and the product's used in eventual disposal; the ability to synthesize new, productive capabilities out of necessary resources; a shift from command and control management to one of leadership, motivation, support and trust; and the emergence of a knowledgeable, skilled, and innovative total work force as the ultimate differentiater of successful companies from unsuccessful ones. Lastly, the book describes six types of virtual organizations and the different circumstances under which a decision might be made to form one.

Granovetter, M. S. (1973). "The Strength of Weak Ties." American Journal of Sociology **78**(6): 1360-1380.

Analysis of social networks is suggested as a tool for linking micro and macro levels of sociological theory. The procedure is illustrated by elaboration of the macro implications of one aspect of small-scale interaction: the strength of dyadic ties. It is argued that the degree of overlap of two individual' friendship networks varies directly with the strength of their tie to one another. The impact of this principle on diffusion of influence and information, mobility opportunity, and community organization is explored. Stress is laid on the cohesive power of weak ties. Most network models deal, implicitly, with strong ties, thus confining their applicability to small, well-defined groups. Emphasis on weak ties lends itself to discussion of relations between groups and to analysis of segments of social structure not easily defined in terms of primary groups.

Hameri, A.P. and J. Nihtila (1995). "Distributed New Product Development Project Based on Electronic Communication - A Case Study. Finland, Helsinki University of Technology.

This paper studies two major new product development projects from the perspective of intergroup communication and interaction. The underlying hypotheses are to examine whether face-to-face communication affects the overall communication in the project and how the geographical distance between actors affects their communication frequencies. Due to the extensive use of electronic communication media the case project provides evidence that the geographic distance between actors do not affect the intensity of communication activities. Yet, organized meeting between individuals do increase the communication activities in the network, although they tend to stabilize very quickly. The project organization and its communication is based on Internet and World-Wide Web, which are not only used to transfer general information and project management reports, but also to provide all collaborators with the engineering data, including drawings, specifications and parameter information. The applied technical platform has proven to be sufficient and functionally adequate for the demands of large multi-national product design and engineering projects. With its user-friendly interface, low and easy accessing costs, together with capabilities to secure the information the platform provides industrial companies an interesting alternative from other commercial applications to control and execute a distributed product development project.

Henderson, R. M. and K. B. Clark (1990). "Architectural Innovations: The Reconfiguration of Existing Systems and the Failure of Established Firms." Administrative Science Quarterly **35**(9-30).

This paper demonstrates that the traditional categorization of innovation as either incremental or radical is incomplete and potentially misleading. This categorization does not account for the sometimes disastrous effects on industry incumbents of seemingly minor improvements in technological products. The authors examine such innovations more closely and, distinguishing between the components of a product and the ways they are integrated into the system (product architecture), define them as innovations that change the architecture of a product without changing its components. They show that architectural innovations destroy the usefulness of the architectural knowledge of established firms, and that since architectural knowledge tends to become embedded in the structure and information-processing procedures of established organizations, the destruction is difficult for firms to recognize and hard to correct. Architectural innovation therefore presents established organizations with subtle challenges that may have significantly competitive implications. The authors illustrate the concept's explanatory force through an empirical study of the semi-conductor photolithographic alignment equipment industry, which has experienced a number of architectural innovations.

Kim, D. H. (1993). A Framework and Methodology for Linking Individual and Organizational Learning: Applications in TQM and Product Development. Sloan School of Management. Cambridge, MA, MIT.

This dissertation explores key issues in organizational learning by providing a framework for integrating individual and organizational learning. Specifically, it identifies mental models as the transfer mechanism through which individual learning becomes operationalized and advances organizational learning. Mental models are described as a critical mechanism for (1) enhancing individual learning by making the individual's learning explicit for that person, and (2) doing so in such a way that the learning can be more easily transferred and diffused throughout the organization as shared mental models. The methodology presented in this dissertation offers a detailed process through which individual learning is translated into organizational learning. According the model of organizational learning proposed, out of those shared mental models will come new organizational actions which will produce new environmental response from which the learning cycle will continue. The product development management case studies describes the full cycle of working with product development managers as a team to translate individual learning into organizational learning and action. Specifically, in identifies two leverage points for managing product development efforts, one of which lists the systemic reasons why a heavyweight program manager with wide authority over the program may be requisite for a successful product development project.

Krackhardt, D. and J. R. Hanson (1993). "Informal Networks: The Company Behind the Chart." Harvard Business Review.

According to David Krackhardt and Jeffrey R. Hanson in "Informal Networks: The Company Behind the Chart," the question of employee relationships cuts to the heart of productivity. In fact, informal relationships contribute more to the real work of a company than official hierarchy. While companies continue to flatten and rely on teams, managers will have to depend less on their authority and more on understanding the interpersonal networks at work within their organizations.

McCord, K. R. and S. D. Eppinger (1993). Managing the Integration Problem in Concurrent Engineering. Cambridge, MA, MIT Sloan School.

Concurrent engineering in large-scale product development generally involves multiple cross-functional teams working simultaneously on separate aspects of the overall development effort. The often complex technical coupling among such teams makes integrating their activities an essential yet difficult task for project management. The authors refer to this challenge of integrating teams as the "integration problem" in concurrent engineering. This paper presents a methodology for determining the needs for integration and coordination by studying the underlying technical structure of a project. The authors use a project modeling tool known as the Design Structure Matrix (DSM) to depict the patterns of required information flow in a project. This matrix representation allows us to identify where coordination is most essential and then to design integration mechanisms based on the specific technical information needs of the project. The utility of this methodology in an industrial setting is demonstrated by an application to the development of a new automobile engine design at General Motors.

Meyer, M. and J. Utterback (1993). "The Product Family and the Dynamics of Core Capability." Sloan Management Review(Spring): 29-47.

Individual products are the offspring of product platforms that are enhanced over time. Product families and their successive platforms are themselves the applied result of a firm's underlying core capabilities. In well-managed forms, such core capabilities tend to be of much longer duration and broader scope than single product families or individual products, The authors recommend a longer run focus on enhancing core capabilities, which includes identifying what they are and how they are applied and synthesized in new products.

Morelli, M. D., S. D. Eppinger, R.K. Gulati. (1995). "Predicting Technical Communications in Product Development Organizations." IEEE Transactions on Engineering Management **42**(3): 215-222.

This work explores prediction of technical communication patterns within product development organizations. Our methodology involves first predicting the patterns of communication and then measuring the actual communications to see if the anticipated linkages are realized. We applied this methodology to a commercial product development project in the electronics industry. In this case study we found that: (1) 81% of all coordination-type communication linkages were predicted in advance; (2) occurrences of frequent communications were more accurately predicted than infrequent communications; and (3) two-way communication exchange was most often observed, even where one-way information transfer was predicted. For the management of product development projects, these results imply that certain aspects of organizational design can be planned by anticipating the technical communication linkages required for project execution. Finally, a critical analysis of our methodology suggests improvements for future work.

Moses, J. (1995). System Design and Management Seminar Lecture, MIT, October 16, 1995, unpublished.

Ohno, T. (1988). Toyota Production System: Beyond Large-Scale Production. Cambridge, MA, Productivity Press.

Pimmler, T. U. and S. D. Eppinger (1994). Integration Analysis of Product Decompositions. ASME Conference on Design Theory and Methodology, Minneapolis, MN.

This paper describes a methodology for the analysis of product design decompositions. The technique is useful for developing an understanding of the "system engineering" needs which arise because of complex interactions between components of a design. This information can be used to define the product architecture and to organize the development teams. The method involves three steps: 1) decomposition of the system into elements, 2) documentation of the interactions between the elements, and 3) clustering the elements into architectural and team chunks. By using this approach, development teams can better can better understand the complex interactions within the system, thus simplifying the development process for large and complex projects.

Pine, J. B. (1993). Mass Customization, The New Frontier in Business Competition. Boston, Harvard Business School Press.

Mass Customization is a new way of viewing business competition, one that makes the identification and fulfillment of the wants and needs of individual customers paramount without sacrificing efficiency, effectiveness, and low costs. It is a new mental model of how business success can be achieved, one that subsumes many of the "silver bullets" of prevailing management

advice such as time-based competition, lean production, and micromarketing. Further, the development of Mass Customization as a paradigm of management explains why product (and service) life cycles are decreasing, why development and production cycle times must follow, why businesses are re-engineering their processes, and why hierarchies are flattening and transforming into networked organizations.

Rechtin, E. (1991). Systems Architecting: Creating and Building Complex Systems. Englewood Cliffs, N.J, Prentice Hall.

Systems architecting combines the theory and engineering of systems with the theory and practice of architecting. Conventional architects, engage in the architecting of buildings. systems architects do the same, but for systems, particularly those in electronics, computers, communications, aircraft, spacecraft, and manufacturing plants. The author feels that a good systems architect should know the engineering fundamentals on which each architecture is based. He or she must also have experience and good judgment. Lastly the architect needs to acquire the insights gained from experience in the design laboratories on the job. The purpose of this text is to help make gaining that experience more efficient by the presentation of heuristics.

Richmond, B. (1993). "Systems thinking: critical thinking skills for the 1990's and beyond." Systems Dynamics 9(2): 113-133.

The problems we face at all levels in the world today resist unilateral solutions. While the web of interdependencies tightens, our capacity for thinking in terms of dynamic interdependencies has not kept pace. As the gap between the nature of our problems and the ability to understand them grows, we face increasing perils on a multitude of fronts. Systems thinking and one of it subsets- system dynamics- are important for developing effective strategies to close this gap. Unfortunately, system dynamicists and systems thinkers have not effectively taught their framework, skills, and technologies to others. The door has not been opened wide enough to let other share our insights with respect to the workings of closed-loop systems. To transfer this understanding on a broad scale, we need a clearer view of its nature and of the education system into which it must be transferred. This article casts some light on what we have to bestow and of the education system that is to receive our bounty. Its intended audience is both system thinkers and educators, and the hope is to help eradicate the distinction between the two.

Rosenthal, S. R. (1991). Effective Product Design and Development: How to Cut Lead Time and Increase Customer Satisfaction. Homewood, Illinois, Business One Irwin.

Time management for new product introduction now runs the risk of oversimplification. As managers are pushed to achieve sizable improvements in product development, they have become absorbed with the element of time, but speed is only one of the measures of performance that must be managed. Elements of quality and cost will always be important too. In product design and development, achieving speed with purpose, and avoiding reckless speed, requires careful management of the whole process. In this book, Rosenthal shows how to shorten the cycle of new product design and development and turn time into a strategic competitive advantage. He offers an integrated managerial view of the design and development process that attempts to help catch design flaws early, correct mistakes, and avoid long development delays.

Sanderson, S. and M. Uzumeri (1994). "Managing product families The case of the Sony Walkman." Research Policy **24**: 761-782.

Success in fast cycle industries (e.g. consumer electronics) can depend on both rapid model replacement and on model longevity. Although Sony was as fast as any of its chief competitors in getting new models to market, an important explanation for the wide variety of models offered by the firm is the greater longevity of its key models. This finding adds an important insight to the conventional literature on time-based competition which emphasizes rapid innovation exclusively. Sony's special understanding of the US market enabled it to respond more effectively to life style differences by locating industrial designers in its key markets. Sony's strong design capability and effective division of labor (engineers lead generational and incremental projects, industrial designers, and market personnel lead topological projects) allow for parallel model development. Investment in manufacturing flexibility amortized over multiple models within the product family make the rapid model changeover possible.

Schein, E. H. (1985). Organizational Culture and Leadership: A Dynamic View. Washington, D.C., Jossey-Bass Publishers.

The purpose of this book is to clarify the concept of "organizational culture" and to show how the problems of organizational leadership and organizational culture are basically intertwined. The author attempts to demonstrate that organizational culture helps to explain many organizational phenomena, that culture can aid or hinder organizational effectiveness, and that leadership is the fundamental process by which organizational cultures are formed and changed.

Simon, H. A. (1990). The Sciences of the Artificial. Cambridge, Massachusetts, MIT Press.

The main thesis of this book is that certain phenomenon are "artificial" in a very specific sense: they are as they are only because of a system's being molded, by goals or by purposes, to the environment in which it lives. If natural phenomenon have an air of "necessity" about them in their subservience to natural law, artificial phenomena have an air of "contingency" in their malleability by environment. The essays in this book attempt to explain how a science of the artificial is possible and to illustrate its nature.

Tyre, M. J. and E. von Hippel (1995). "The Situated Nature of Adapted Learning in Organizations," MIT Sloan School of Management. Working paper no. 3568.

This paper explores the nature of adaptive learning around new technology in organizations. To understand this issue, the authors examine the process of problem solving involving new production equipment during early factory use. They find that adaptation is a situated process, in that different organizational settings (1) contain different kinds of clues about the underlying issues, (2) offer different resources for generating and analyzing information, and (3) evoke different assumptions on the part of problem solvers. Consequently, actors frequently must move in an alternating fashion between different organizational settings before they can identify the causal underpinnings of a problem and develop a suitable solution. These findings suggest that traditional, decontextualized theories of adaptive learning and of collaboration could be improved by taking into account that learning occurs through people interacting in context, or more specifically, in multiple context. Learning is often enhanced not just by bringing people together, but by moving them around to confront different sorts of clues, gather different kinds of data, use different kinds of tools, and experience different pressures relevant to a given problem. The authors discuss both managerial and theoretical applications of these findings.

Ulrich, K. (1995). "The Role of Product Architecture in the Manufacturing Firm." Research Policy **24**(3): 419-441.

Product architecture is the scheme by which the function of a product is allocated to its physical components. This paper further defines product architecture, provides a typology of product architectures, and articulates the potential linkages between the architecture of the product and five areas of managerial importance: (1) product change; (2) product variety; (3) component standardization; (4) product performance; and (5) product development management. This paper is conceptual and foundational, synthesizing fragments from several different disciplines, including software engineering, design theory, operations management and product development management. This paper raises awareness of the far-reaching implications of the architecture of the product, creates a vocabulary for discussing and addressing the decisions and issues that are linked to product architecture, and identifies and discusses specific trade-offs associated with the choice of a product architecture.

Ulrich, K. and S. Eppinger (1995). Product Design and Development. New York, Mc-Graw Hill, Inc.

This book contains material developed for use in an interdisciplinary graduate course on product development at MIT. It blends the perspectives of marketing, design, and manufacturing into a single approach to product development. Students are provided with an appreciation for the realities of industrial practice and for the complex and essential roles played by various members of product development teams. Industrial practitioners are provided with a set of product development methodologies that can be put into immediate practice on development projects.

von Hippel, E. (1990). "Task Partitioning: An Innovation Process Variable." Research Policy 19: 407-418.

Innovation projects are "partitioned" into smaller tasks. Precisely where the boundaries between such tasks are placed can affect project outcome and the efficiency of task performance due to associated changes in the problem-solving interdependence among tasks. The author propose that problem-solving interdependence among tasks can be predicted in many projects and then can be managed by strategies involving (1) adjustment of the task specifications and/or (2) reduction of the barriers to problem-solving interaction across selected or all task boundaries. The potential value of studying and managing task partitioning is illustrated by exploring how problematic areas of the innovation process, such as the design-build and marketing-R&D interfaces, can be better understood through that lens.

Wheelwright, S. C. and K. B. Clark (1992). Revolutionizing Product Development, Quantum Leaps in Speed, Efficiency, and Quality. New York, The Free Press.

This book presents ideas that have been tested in research and in classroom interactions with hundreds of executives, and put into practice in many companies. These ideas focus on the engineering process that lies behind new products, the integration of marketing, manufacturing, and engineering, and in particular, the role of senior management in leading and guiding the effort. Concepts are laid out for the effective organization and management of product and process development.