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The Coupling of Product Architecture and Organizational Structure Decisions

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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.

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I. Introduction

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.

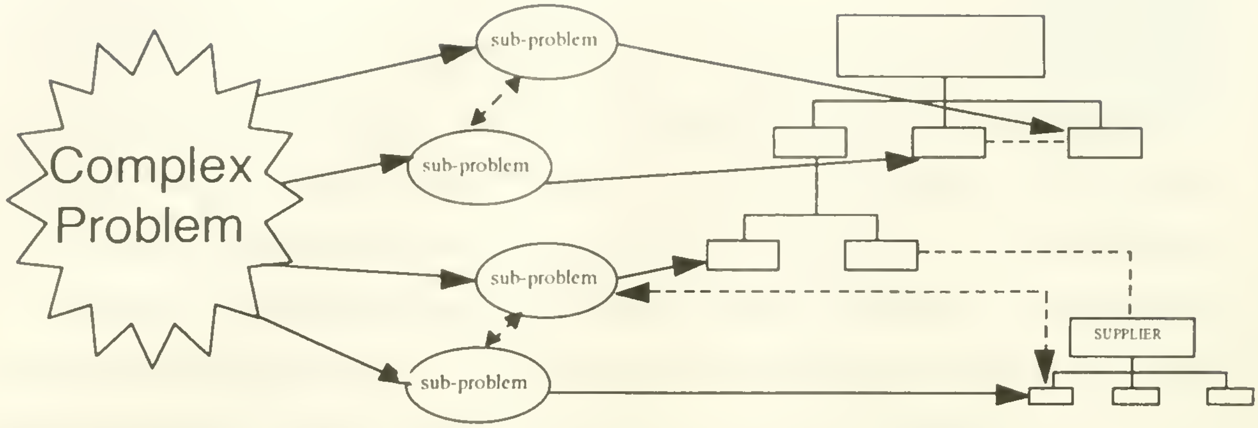

Figure 1. Problem Decomposition and Organizational Assignment. The organization must decompose the complex problem and allocate tasks to the product development team (solid arrows). Additionally, information must be coordinated across individuals, teams, and suppliers (dashed arrows).

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,

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[1] Intermediate forms refers to prior architectural or organizational structures.

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.

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].

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.

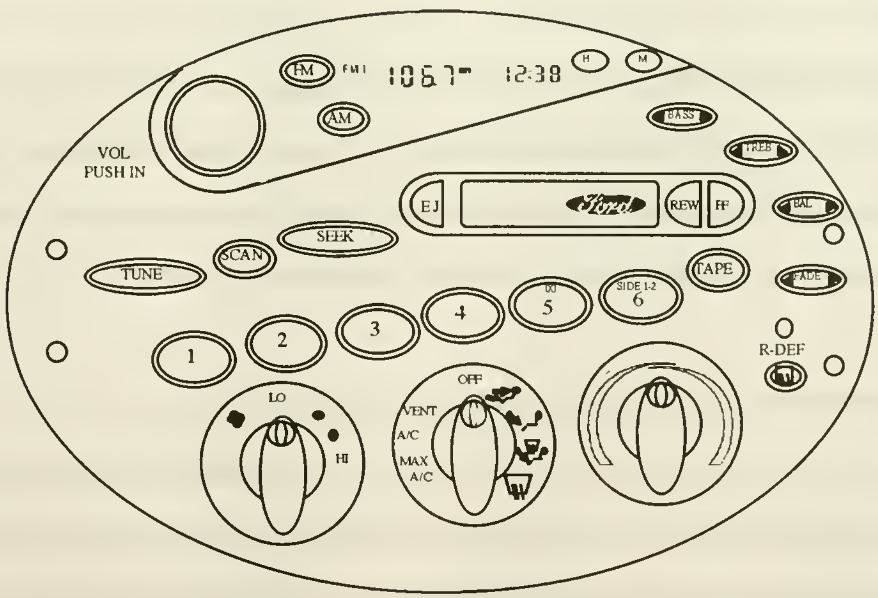

Figure 2. Ford's Integrated Control Panel

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].

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.

II. 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.

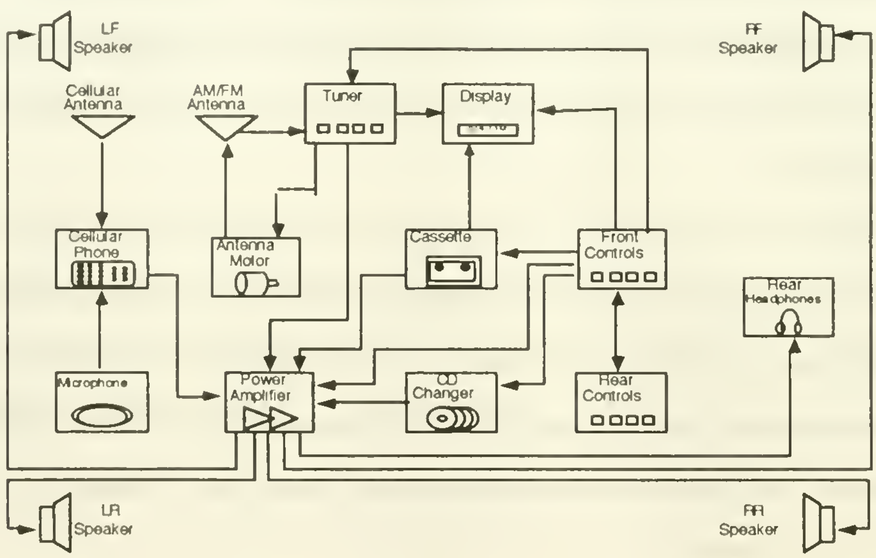

Figure 3. Audio System Architecture.

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.

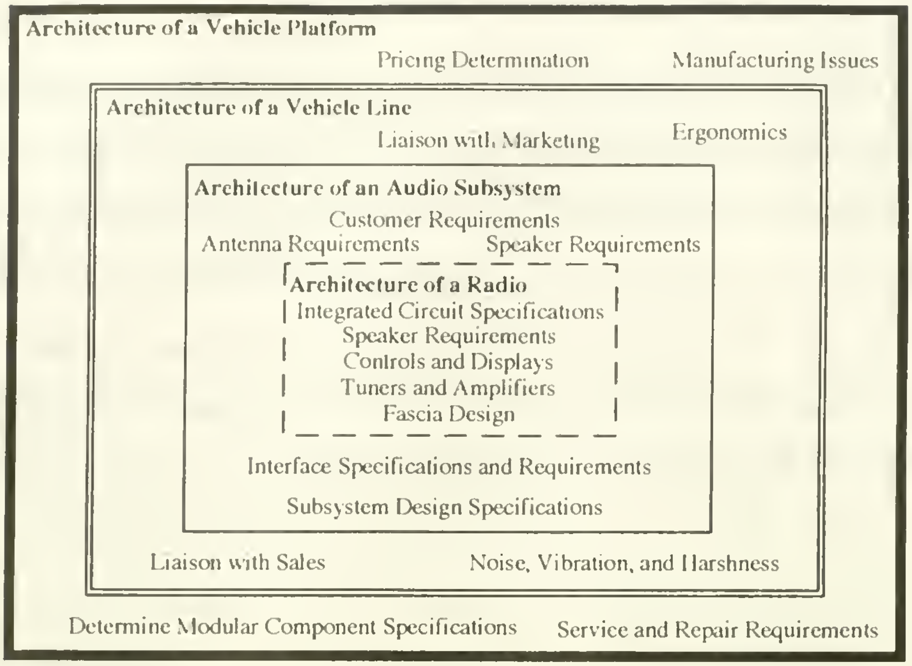

Figure 4. A nested hierarchy of product architectures.

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.

III. Discussion of Findings

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.

A. 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.

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.

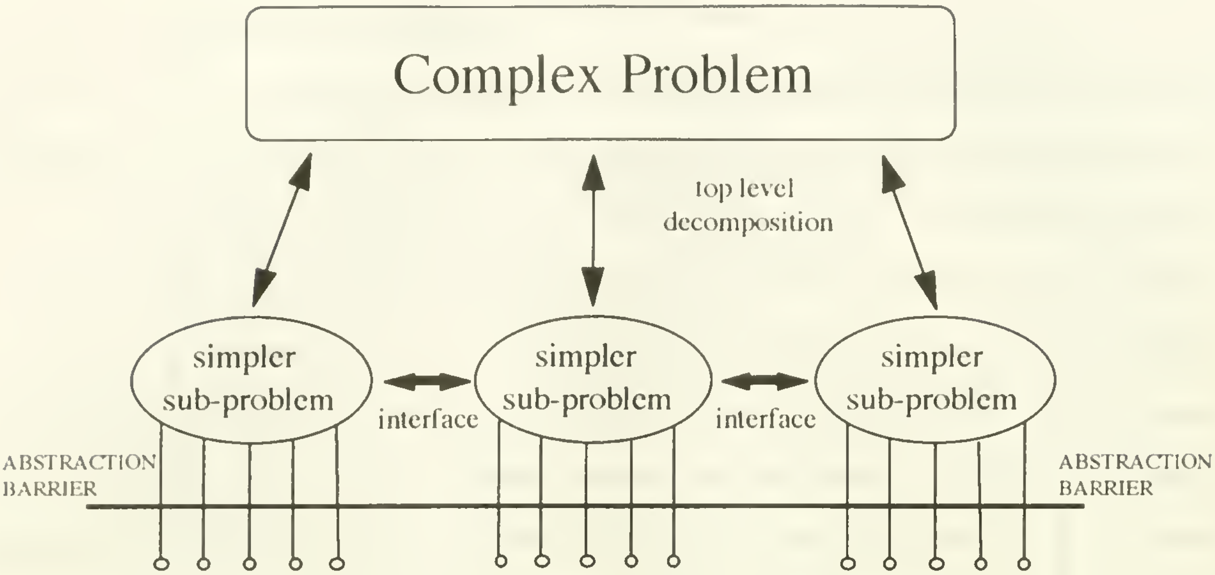

Figure 5. Problem Decomposition and Abstraction

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.

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.

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.

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.

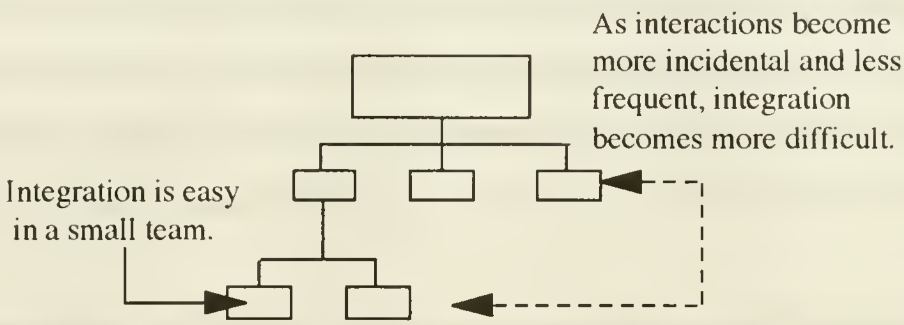

Figure 6. Interactions in an organization

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.

B. 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.

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].

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].

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.

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.

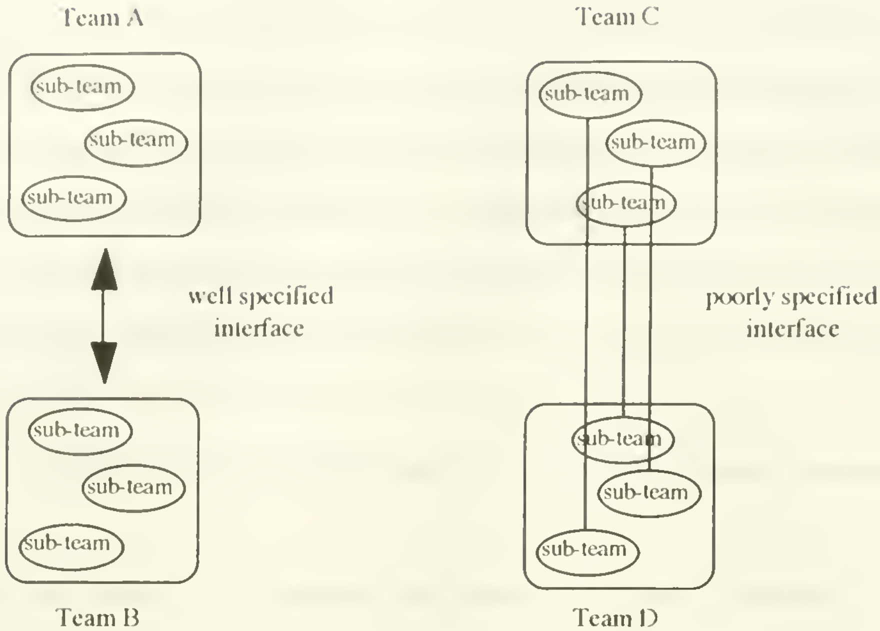

Figure 7. A well specified interface between Teams A and B allows for less formal co-location methods. However, co-locating Teams C and D would facilitate the high-frequency interactions.

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.

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.

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.

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.

IV. Conclusion

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].

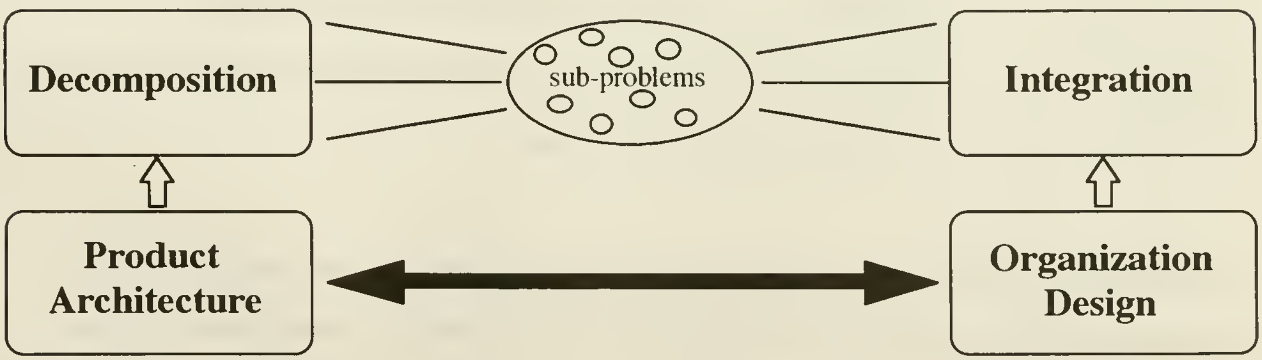

Figure 8. Problem Relationships

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.

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?

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