Architectural Disruption in Aerospace

By

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ABSTRACT

Distinctive technology and customer / supplier relationships are currently the primary sources of competitive advantage in the Aerospace industry. Modular Open System Architecture (MOSA) requirements represent a significant disruption to this mode of competition. The United States Department of Defense intends to accelerate the rate of aerospace innovation and inject additional competitiveness into the procurement process through the modularization of its products and effective intellectual property management. This combination of architectural disruption and new customer capabilities has the potential to reduce the industry's opportunity to capture value from innovative technologies or a position as first supplier.

Historical examples such as Polaroid and IBM demonstrate the organizational paralysis that often results from disruptions in product architecture. The competitive formula becomes ingrained in the processes, resources, and culture of mature companies and is no longer explicit knowledge, which limits the company's ability to develop the capabilities required to compete in its new environment. Competing in a MOSA environment will require the development of new organizational capabilities such as rapid experimentation, fighting standards wars, and protecting system-level knowledge. Defining the disruptive threat and the foundations of current core competencies will enable firms to develop the organizational capabilities essential for this shift in competitive context.

The author will present several historical examples of architectural disruption, a framework for evaluating the disruptive change, and an identification of organizational anchors that may hinder a particular competitor's ability to respond to MOSA. The goal of the thesis is to start a dialogue within an identified incumbent with in hopes of beginning the organizational transformation required to effectively compete in this new era.

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Table of Contents

Table of Figures

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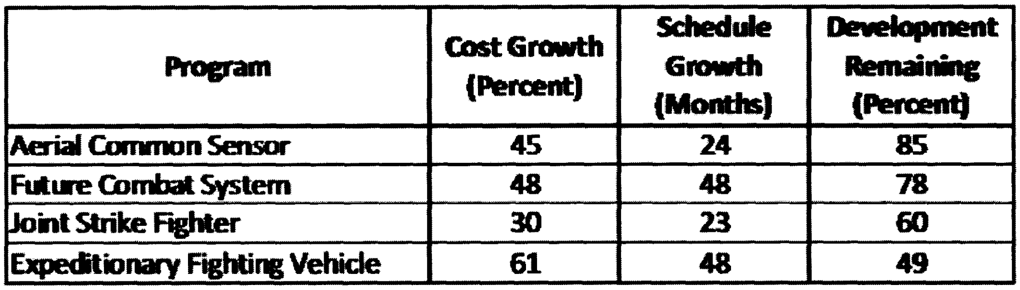
1. Introduction

1.1. U.S. Department of Defense Acquisition Program Performance

The U.S. Department of Defense (DoD) is under greater pressure than ever to develop innovative capabilities in response to rapidly changing threats. However, weapon system development programs are taking 2-3 times longer than they were 30 years ago and extensive cost overruns and delivery delays have become the norm rather than the exception. These advanced technology development programs inherently involve substantial cost and schedule risk as the scope of the effort required to develop these technologies is often unknown. The DoD and its suppliers continuously attempt to identify and mitigate these risks. Yet many large acquisition programs far exceed their initial budgets and schedules (Figure 1).



Program	Cost Growth (Percent)	Schedule Growth (Months)	Development Remaining (Percent)
Aerial Common Sensor	45	24	85
Future Combat System	48	48	78
Joint Strike Fighter	30	23	60
Expeditionary Fighting Vehicle	61	48	49

Figure 1: Cost and Schedule Growth of Selected DoD Programs.
(Pre-Milestone A and Early-Phase Systems Engineering, National Research Council, 2008)

The DoD spends billions of dollars every year on procuring equipment and research and development services from the private sector. The Federal Acquisition Regulation (FAR) creates a single framework by which the DoD manages procurement programs for everything from duct tape to fighter jets. However, unlike duct tape, the government must develop and build fighter jets itself since no commercial market exists. The DoD contracts private aerospace companies to design, manufacture, and support such systems. While the Federal Acquisition Regulation's successes are visible in technological achievements of systems such as the Global Positioning System (GPS) and the F-22 Stealth Fighter, its ability to rapidly and affordably deliver the new warfighting capabilities the DoD requires is being called into question.

The FAR relies heavily on inter-supplier competition to maximize the DoD's purchasing power and incentivize desired contractor behavior. However, recent defense industry consolidation has weakened the DoD's negotiating position. Boeing now includes former industry members Rockwell International Aerospace, McDonnell-Douglas Aerospace, Hughes Helicopters, and Litton Precision Gear and is the only major American airliner manufacturer. Industry consolidation is at least as great around the other three prime contractors; Lockheed Martin, Raytheon, and Northrop Grumman. Consolidation has enabled these prime contractors to diversify and better adapt to the volatility induced by changes in defense spending. However, this reduction in sources of supply for its technology needs has served to reduce the DoD's ability to apply competitive pressure to the procurement process. While the effect of this consolidation on acquisition program performance is debatable, the DoD perceives that it diminishes its ability to affordably procure technology.

During the mid-20th century, the United States Department of Defense led the world in its ability to develop cutting edge technology. Now the commercial sector is leading in development of new technology and the present rate of innovation in the commercial sector often outstrips improvements in DoD weapon systems. Due to the length of the procurement process and the current rate of innovation, systems can become obsolete before they are fielded. The DoD responded to this challenge by identifying methods for leveraging the competitive prices and rapid innovation found in the commercial markets.

In the early 1990s the DoD mandated the use of COTS (Common Off The Shelf) parts whenever possible. Increased use of technologies applicable to both the commercial and military sectors allows the DoD to leverage the cost, performance, and quality benefits of commercial innovation and economies of scale. Utilizing commercial equipment was hoped to enable the DoD to obtain high quality, competitive prices, on-time delivery, and the latest technology with little or no Government investment. However, mandating the use of COTS parts has not resulted in a significant procurement performance improvement. Fighter planes and aircraft carriers are large, complex, and highly integrated systems. Their closed integrated system architectures with proprietary non-standardized interfaces leave few opportunities to leverage COTS equipment. The DoD requires new system architectures that enable it to utilize the state-of-the-art technology and competitive pricing found in commercial markets to improve acquisition performance.

The ever-increasing scale, complexity, and required performance of these weapon systems are driving much of the cost and schedule growth on development programs. For example, the DoD's Net-centric effort to integrate every facet of warfighting into a cohesive force requires more weapon systems to communicate and coordinate their activities with each other which increases system complexity. The F-35 Joint Strike Fighter, currently in development, is an enormously sophisticated aircraft that is required to be four times more effective than legacy fighters in air-to-air combat and eight times more effective in air-to-ground combat. The F-35 will soon be the world's most technologically advanced fighter. At the same time, the F-35 is expected to improve on affordability and maintainability over previous fighter generations. The scale and complexity of these systems are amplifying the effort required to mitigate technology challenges as they arise in the development process. The budgets and schedules of their development programs will continue to climb unless the government and Aerospace can better manage system complexity.

1.2. Modular Open System Architecture Requirements

In order to effectively improve the performance of the FAR procurement process, the DoD required an innovative approach to inject additional competitive pressure into the procurement process, reduce design complexity, create additional opportunities to leverage commercial sources of innovation, and drive in economies of scale. In the early 1990s, the computer industry and the Internet provided the inspiration for such an approach. The modular architecture of the personal computer was accelerating the rate of technology innovation and made computers increasingly affordable. The internet's open architecture created an information platform that allowed PCs built by various manufacturers to communicate across the world. These lessons helped the Department of Defense to recognize the interdependency between its product architectures and its procurement capabilities. In response the DoD created Modular Open System Architectures (MOSA) requirements, an architectural strategy that exploits the concepts of *Modularity* and *Openness* to improve acquisition program performance. The goals of MOSA are to:

- Rapidly and efficiently create new warfighting capabilities
- Provide access to world class design, production, operation and support capabilities
- Inject additional competitive pressure into the procurement process

In November 1994 the Under Secretary of Defense for Acquisition, Technology, and Logistics, Paul G Kaminski, established the Open Systems Joint Task Force (OSJTF) to "sponsor and accelerate the adoption of open systems in electronics included in weapons systems acquisitions." The goals of the OSJTF were to:

- Make MOSA an integral part of the acquisition process
- Provide expert assistance in applying MOSA
- Ensure application of MOSA by all acquisition programs
- Collaborate with industry to ensure a viable open standards base

As directed, the OSJTF established a policy for modular open systems in weapon system acquisition. In May of 2003 this policy was then incorporated in DoD Directive 5000.1, "The Defense Acquisition System," and into DoD Instruction 5000.2, "Operation of the Defense Acquisition System." Additionally, in September 2004, the Open Systems Joint Task Force published the program manager's guide "A Modular Open Systems Approach to Acquisition" to facilitate the cultural adoption of MOSA and enforcement of their specifications. As of October 2004, all DoD acquisition programs are now subject to a milestone review and must brief their program's MOSA implementation status to the Milestone Decision Authority for OSJTF's MOSA policy compliance.

It took several additional years for the MOSA policy to be adopted by the acquisition community and Aerospace industry and only recently have acquisition programs included strong contract language requiring MOSA compliant system designs. These are large mature organizations and it will take time to completely socialize and integrate MOSA into the procurement cycle. As acquisition programs can last for years or even decades, it will take even longer to evaluate if the promised MOSA benefits materialize. However, the impact of the OSJTF's MOSA policy on the Aerospace industry's competitive context is already becoming apparent. Defense contractors are advertising fully MOSA compliant systems as a source of competitive advantage versus competitors with closed and integrated system architectures. The DoD is leveraging MOSA to inject additional competitive pressure even after contract award. Modular Open System Architecture is demonstrating a potential to significantly disrupt the business models and competitive context of the Aerospace contractor industry.

1.3. Thesis Structure

The objective of this thesis is to define the disruptive potential of the DoD's MOSA procurement strategy for the U.S. Aerospace industry. This will be accomplished by:

- Defining modularity and openness
- Examining the connection between product and enterprise architectures
- Presenting relevant historical examples of disruption
- Providing a framework for characterizing the impact of MOSA on the competitive context
- Suggesting strategies that may be effective in competing in a MOSA procurement environment

MOSA has the potential to be extremely disruptive to the industry in some product lines. MOSA is a subtle shift in the competitive context for Aerospace firms. This subtlety combined with Aerospace's organizational complexity and causal ambiguity will make it extremely difficult for these firms to avoid disruption. Hopefully, this thesis will help Aerospace to begin the organizational transformations required to effectively compete in this new era. The key ideas that the reader should take away are:

1. MOSA is NOT just new technical requirements, it is an embodiment of changing customer values and new procurement capabilities
2. Aerospace should anticipate a change in ways in which their customers value, purchase, and use their products
3. Contractors that deliver the specialized capabilities desired by its customers will capture greater value from programs
4. Organizational beliefs will determine Aerospace's ability to effectively respond to MOSA

2. Modular and Open Product Architectures

2.1. *Definition of Modularity*

To identify the possible implications of MOSA on the defense contractor business model, it is important to understand what modular product architectures are and are used for. Modularity is a characteristic of a product's architecture, or the allocation of its functionality to its physical components. Product architecture is defined by (Ulrich, 1995):

- The arrangement of functional elements
- The mapping from functional elements to physical components
- The specification of the interfaces between these physical components.

A product's architecture can have an enormous impact on the performance of the design process, product, and firm. The product's architecture can determine what skills are required to contribute to the design, how flexible the product is in adapting to changes in technology and user's needs, and how easy it is to manufacture. Modularization of a product's architecture is often used as a strategy for mitigating complexity and providing process, product, and firm flexibility by minimizing the cost and complexity of product changes.

Modular architectures minimize the cost of change by localizing the effects of design changes to as few product components as possible. Modular architectures are arranged into modules, which are groupings of system components that are strongly related in function and weakly related to other components. The degree to which functionality can be allocated to single components determines the relative modularity of the system. Truly modular designs have a one-to-one mapping of functions to modules. The functional mapping of the trailer in the following figure demonstrates such one-to-one mapping between modules and their functions.

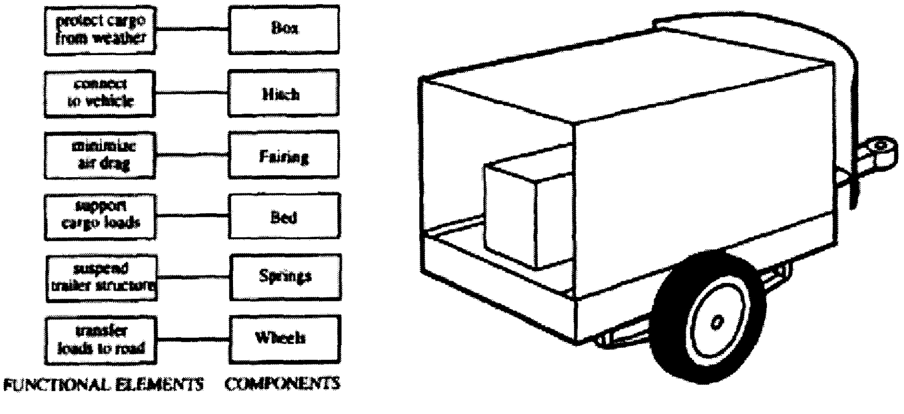


Figure 2: Trailer Exhibiting Modular Architecture – Source: Ulrich, 1995

This one-to-one mapping of function to physical modules enables flexibility of the product's functionality by minimizing the complexity and cost of design changes. If the designer wished to change how the trailer connected to the towing vehicle, this change would likely only impact the hitch and leave the remaining modules unchanged. Modular architectures are contrasted by integral architectures that have non one-to-one mappings of functions to physical modules. The following figure demonstrates integral architecture.

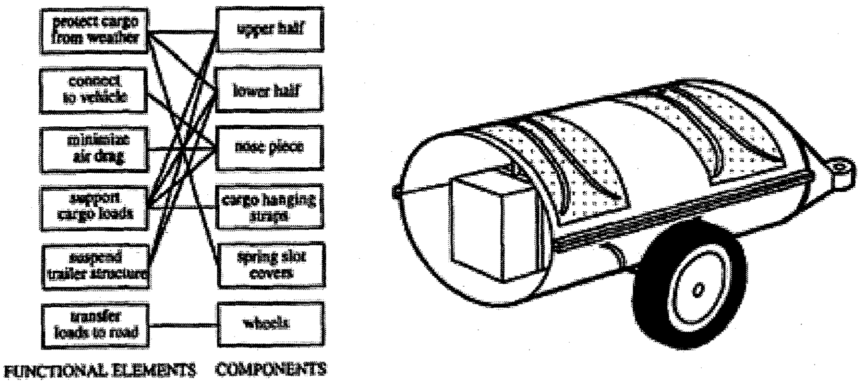
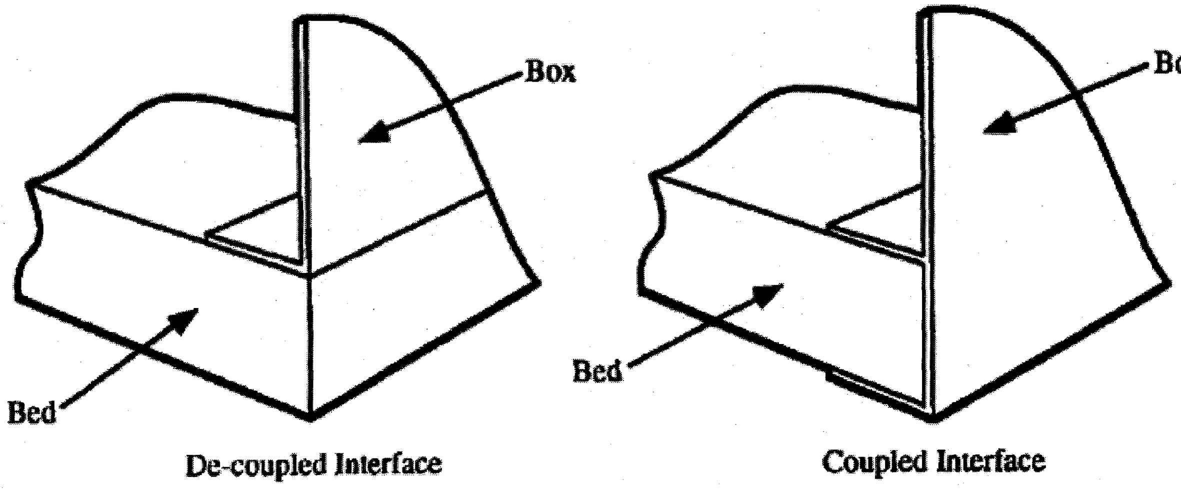


Figure 3: Trailer Exhibiting Integral Architecture – Source: Ulrich, 1995

If our designer wished to change how this trailer connected to the towing vehicle, the change would only impact the nose piece. However, the nose piece in this architecture is also responsible for both minimizing air drag and supporting the cargo loads. This design change is significantly more complicated in the integral architecture since we must now ensure that the nose piece still adequately performed these functions after changing the hitch. This increased complexity may require additionally skilled labor, time, or manpower to complete the design change.

Modular design's one-to-one mapping of functions to modules is a powerful method for facilitating changes through the minimization of change complexity. However, to ensure that the impact of a design change is localized to a single module, modular designs also employ de-coupled interfaces. Two modules are said to be coupled if a change made to one component requires a change to the other component in order for the overall product to work correctly. The following figure demonstrates the difference between coupled and de-coupled interfaces.



De-coupled Interface

Coupled Interface

Figure 4: Coupled Vs De-Coupled Interfaces (Ulrich, 1995)

If our trailer utilized the above coupled interface, any change to the trailer box design would require consideration of the bed design. However, the modular trailer architecture with its de-coupled interfaces allows changes in the box design with minimal consideration of the bed design. De-coupling further minimizes the complexity of design change by ensuring change localization.

In order to maximize the modular design benefits of change localization, system behaviors, such as heat generation and vibration, should also have as close to a one-to-one mapping to physical components as well. This behavioral allocation minimizes the complexity of behavior management. Often design disciplines are strongly related to specific system behaviors, and a one-to-one mapping between behaviors and modules enables modularization and specialization of the design team. In this way, the various engineering –ilities can focus their attention on the specific modules that impact their behavior of concern. For example, mechanical engineers can be assigned to modules where heat and vibration management is important and electrical engineers can be assigned to modules where managing electrical interference is critical. Facilitating this skill specialization and limiting the quantity of architectural knowledge required to effectively design a module is an important aspect to reducing the cost and complexity of design change.

To ensure that unintended leakage of system behaviors between modules does not occur, management of inter-module interactions is critical. Ideally, modular architectures limit interactions between modules to predefined module interfaces. Additionally, only predefined interactions occur at these interfaces. Through effective functional and behavioral management, the architect can modularize both the system's physical components and the design information. The ability of architects to identify and manage functional and behavioral coupling between modules will ultimately determine their ability to mitigate complexity in the design and improve the effectiveness of the design process.

	Modular	**Integral**
Arrangement of functional elements	Modules	Chunks
Mapping from functional elements to physical components	One-to-One	One-to-Many
Specification of the interfaces	De-coupled	Coupled
Mapping of system behaviors to physical components	One-to-One	One-to-Many
Interactions between physical components	Predefined	Unknown
Location of interactions	Interfaces	Unknown

Figure 5: Characterization of Product Architectures

2.2. *Modular Design Processes*

As the modularization of a product's architecture can take significant time and effort, modularity is an investment made by the firm to create flexibility of design, production, and use. However, the return on the firm's investment will fail to materialize without proper planning and execution of the design process. Modularity requires that the functions, behaviors, and performance specifications are decomposed and allocated to as few modules as possible while utilizing decoupled interfaces between these modules. To ensure that this decomposition and allocation process results in effective modularization, a design specification allocation process advocated by modularity experts Caliss, Baldwin and Clark, starts with a partitioning of all design information into visible and hidden "Design Rules." Visible Design Rules define the modules, the interfaces, and the tests that validate that a module conforms to the modularization strategy and demonstrates the desired functionality and behavior. Hidden Design Rules covers all of the various module design decisions that do not affect the system beyond individual modules.

Visible Design Rules			Hidden Design Rules
Architecture	**Interfaces**	**Standards**	
What modules are part of the system and their functions are	How will modules interact, fit, connect, communicate	Testing a module's conformity to the design rules and measuring performance	Module specific design information

Figure 6: Partitioning of Design Information (Caliss, Baldwin and Clark, 2003)

Managing these dependencies and creating an effective modularization strategy require an abundance of product, firm, and environmental information to establish the "Design Rules" and modularize successfully. Effectively partitioning the design information up-front is difficult because architects often cannot completely define all of the design parameters of the system until the system manufactured and fielded. The system level information required for modularization strategy can include:

- Modularity-enabled design, production, and use capabilities desired
- Knowledge of all design, production, and use domains
- Ability to validate the functionality and behavior of designs before production
- Complete understanding of product / environmental interactions

Design Structure Matrices (DSM) is one of many tools that architects often utilize to map design parameters and their dependencies. Design parameters of the modules are itemized along the rows and columns of the matrix. Interactions between design parameters are then marked. The following figures demonstrate the effective partitioning of design information between design teams and physical modules.

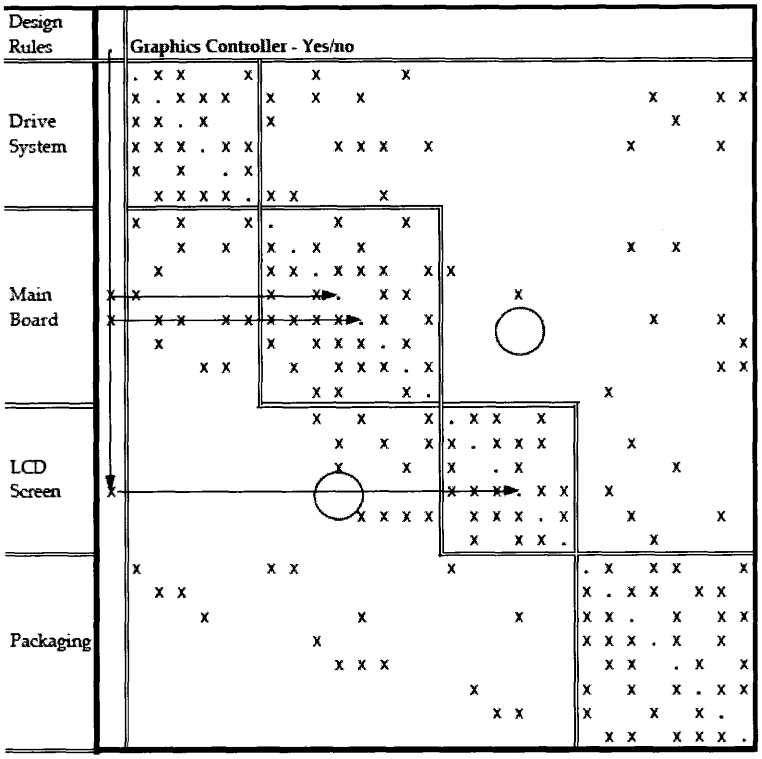


Figure 7: Design Structure Matrix – Integral Product Architecture – Source: Carliss, Baldwin, Clark 2003

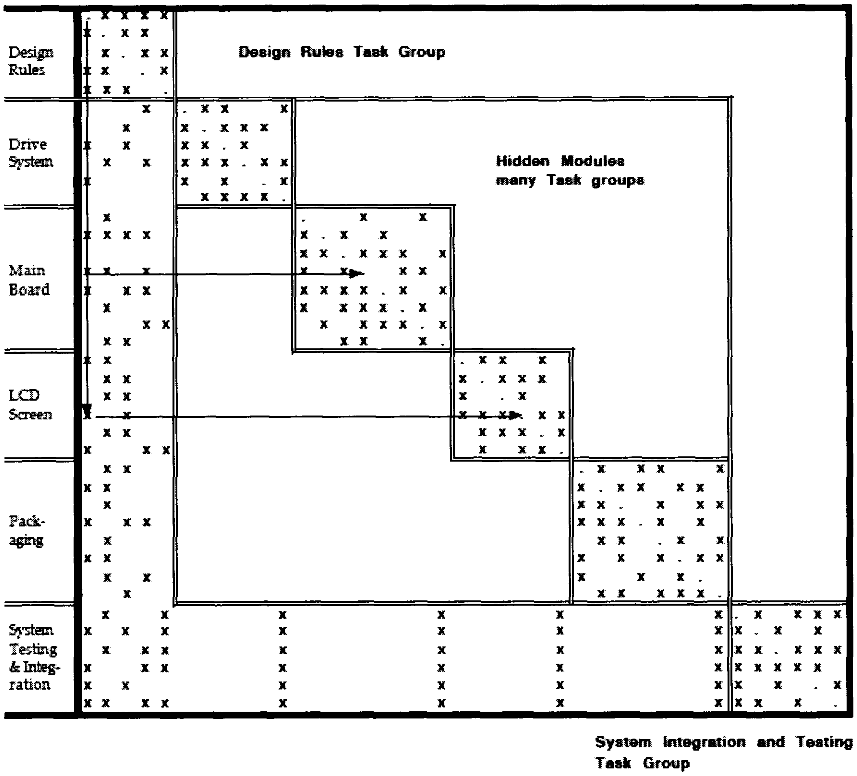


Figure 8: DSM Modularization Through Partitioning – Source: Carliss, Baldwin, Clark 2003

Notice that after partitioning the design parameters, the Design Rules Task Group controls a subset of the design specifications for all modules and that the specifications that are not under its control are "hidden" within one module. This partitioning of information creates the Visible and Hidden design rules required for effective modularization. The complexity of design decisions is significantly reduced and the various design teams are now able to work independently and in parallel.

Design dependencies are not limited to product parameters and can often arise from the production, business, or environment domains. There are also often physical and legal reasons for design dependencies. DSMs that map design parameters to people, manufacturing equipment, or other resources are useful tools for identification of design dependencies arising from domains other than engineering. These dependencies can change with the emergence of new designs, manufacturing processes, and technology. Continuous identification of hidden dependencies is a required organizational capability if the modularization strategy is to be successful.

The tenants of modular design serve as a useful framework for guiding the identification and design of modules (Flowers K, Azani C, 2004). Under this framework, a design is said to be truly modular if its modules demonstrate cohesiveness, are well encapsulated, are self-contained, and are highly binded.

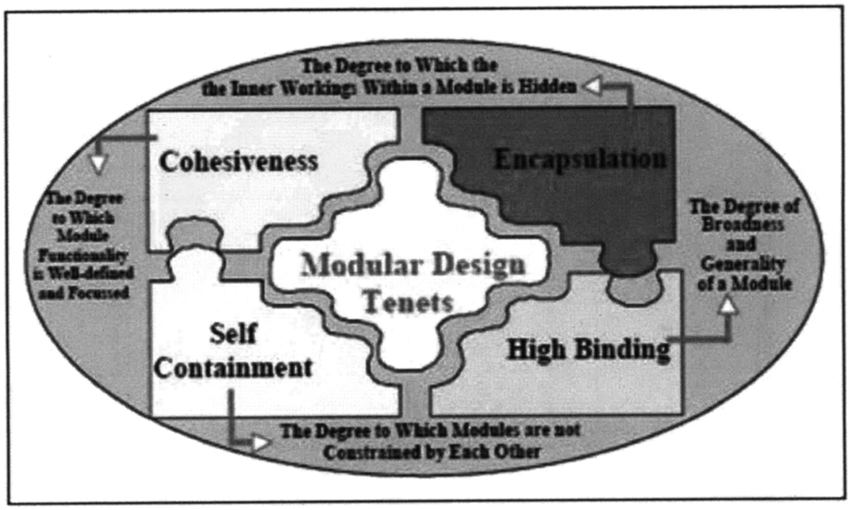


Figure 9: Tenets of Modular Design – Source: Flowers K, Azani C, 2004

A module is defined to be highly cohesive if all of the functionality assigned to it is strongly related. For example, a monitor that was intended to both display visual information and project sound would demonstrate low cohesion since these functionalities are not strongly related. A module would be described as well encapsulated if it hides the internal workings of the module from the rest of the system. A PC's hard drive is a well encapsulated module since a change in data storage technology does not impact the rest of the system. System modules are defined to be self-contained if they do not constrain the design or performance of other modules. If our hard drive required so much system power that it affected the remaining design of the system, then its design is not well contained. To enable the goals of commonality and reuse, each of the modules must be highly binded, meaning that the modules uses broad and general definitions of functionality. For example, if we were to define many categories of hard drives each with their own specialized functionality and interfaces, the selection of drives we could use for our desktop computer would narrow to drives that met our particular system function and performance needs. Adherence to these tenants of modularity will minimize unintended module interaction, maximize product flexibility and mitigate design complexity.

As design dependencies and design requirements change over the course of the design process, it is important to continually assess the success of the modularization strategy. The first step is to verify that all of the important design parameters (requirements, functions, behaviors, and interfaces) have been accounted for and allocated to the system. Additionally, compile a list of all the desired capabilities that are created through modularity of design, production, and use. For example, modules intended for outsourcing should be divided from the rest of the design effort to as great an extent as possible. Any remaining visible parameters allocated to the outsourced module should be stable and closely managed parameters to minimize the interaction required between the module and the internal system design teams. The degree to which the parameter allocation creates the desired design capabilities dictates the success of the modularization strategy.

The explicit management of interfaces and standards is extremely important during the design of modular products if the modularity-enabled benefits of complexity mitigation and flexibility are to be conferred to the design team. Stable decoupled interfaces and standards are important to minimizing the amount of system-level knowledge required of module designers as they eliminate the impacts of external design changes. Managing interfaces and standards is also important when interoperability, extensibility, reusability, or maintainability is key product requirements as they facilitate compatibility with externally sourced modules and third party support of the system.

2.3. Limitations of Modularization in Practice

Modular product architectures potentially create enormous value for both the design firm and the customer. However, there are several limitations on the architect's ability to modularize a system in practice.

- Systems have interactions that are beyond control of the designer
- Functional performance is determined by multiple modules (weight, power, size, etc)
- Limitations of design tools to model interactions and validate system modularity
- Cost of interfaces on design complexity
- Cost of interfaces on system level performance
- Constraints of modularity on performance optimization
- Hidden system integrality

Systems often exhibit inherent integrality and have functional or behavioral interactions that are beyond the control of the architect. System level performance attributes, such as the acceleration of a car, are typically determined by modular attributes such as mass and size. Every component of a car will contribute to its ability to accelerate and will prevent the architect from mapping this function to a single module.

The architect's ability to decompose a system into modules can also be limited by the capability of design tools available. Many physical processes and system behaviors currently cannot be modeled or decomposed well. Designs in high-power applications, such as the design of jet engines, where large quantities of heat and force are present are particularly difficult validate through modeling. These forces cannot be isolated to one module and the behavior of the module cannot be decoupled from other interfacing modules. Often the modules must be designed and manufactured, then validated physically when they are integrated with other components. The system design and interfaces must then be tailored to the behavior exhibited by the integrated system. The ability of the architect to model and validate system-level performance prevents modularization of the design.

In an effort to modularize a system and allocate single functions to modules, the architect can introduce interfaces where they are not required by the system. Functional decomposition and the addition of interfaces can increase the actual complexity above the essential complexity of the system. The following figure demonstrates an increase in system complexity from the introduction of an interface that raises the number of component connections from six to eight.

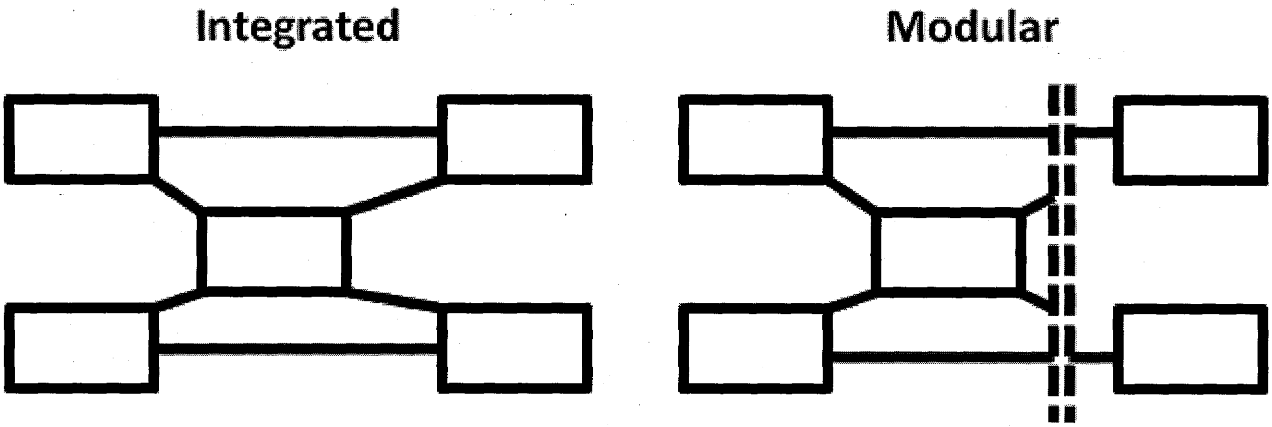


Figure 10: Introduction of an Interface Increasing System Complexity

While modularization can provide many benefits to the firm and customer, it often incurs a cost. Each additional interface can incur a performance penalty on the product and the design process. The effort required to manage interfaces increases with each additional interface. Additionally, these interfaces can incur a penalty to system-level performance. In an effort to minimize module interactions with decoupled interfaces, systems can quickly become "boxes of boxes." In physical systems, each additional box can add mass, surface area, or cost which become penalties to overall system performance.

The required level of system performance can also limit the architect's ability to modularize the system as opportunities for performance optimization often exist between the design options presented by the modular architecture. This trade between modularity and system performance can be seen in the evolution of the personal computer. Modularity has facilitated the rapid incremental innovation of the CPU. However, the traditional modular architecture of the PC is increasingly unable to mitigate the additional heat generated by exponentially growing number of transistors inside the CPU. The need to continually improve performance is driving the industry towards ever increasingly integrated system architectures with advanced heat dissipation technologies. In fact, Intel's ability to deliver integrated CPU and motherboard designs that effectively managed heat was a major factor in Apple's decision to move from IBM to Intel's computing platform.

Note that many system architectures, such as the PC, may appear modular in the design domain, but in reality are not. Architectural dependencies arise from domains beyond the purely technical. Monetary, regulatory, and intellectual property rights often result in unplanned coupling between modules. For example, the use of a hazardous material may require specialized manufacturing processes or facilities that could limit the design options available to the rest of the system. Integrality can even be hidden by the design process itself. Designers often mitigate module interactions on the fly without formal dependency management. For example, reliability specialists routinely mitigate difficult to isolate system behaviors such as vibration, heat, and power through overdesign of the module components which hides the inherent integrality of the design from the rest of the system. Without effective dependency mitigation capabilities, the firm will be unable to execute its modularization strategy.

2.4. Firm Benefits of Modular Design

Modularization is an investment by the firm in flexibility and the reduction of complexity. It creates numerous product, organizational, and customer capabilities through the minimization of the cost and complexity of change. These capabilities result in numerous benefits to the firm which includes:

Mitigation of design complexity:
- Reduction in design scope
- Skill specialization
- Enablement of concurrent engineering
- Rapid experimentation / product improvement
- Reduced cost of change
- Accommodation of future uncertainty
- Reduction of design risk

Establishment of Product Platforms:
- Facilitates reuse
- Accelerates time to market
- Reduces development costs
- Flexibility in application and function

Many of modularization's benefits result from the reduction in design complexity. The modularization Design Rules (product architecture, interfaces, and standards) captures much of the system's architectural information. These Design Rules greatly reduce the complexity of the system for designers as a much smaller scope of system knowledge is required to effectively contribute to the system. This reduction in scope allows a module design team to specialize in the engineering disciplines, technologies, and processes specifically required to realize a single module. Skill specialization can result in improved design process effectiveness and product innovation. Modularization of the product architecture and design information also greatly simplifies the interaction between module design teams. If the product is truly modular each team can proceed concurrently and the design team itself can modularize and design each module concurrently, rather than in series. Concurrent design processes can result in accelerated design schedules and budgets.

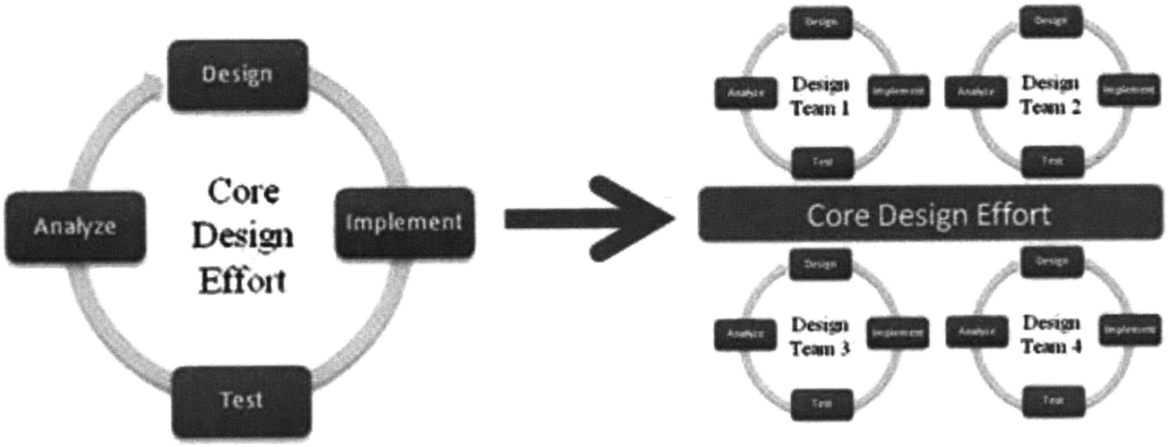


Figure 11: Concurrent Design Enabled Through Modularization

All technology development involves some level of design risk. As the design process proceeds and problems with the design materialize necessitating a change in the product, modular architectures limit the scope of their impact. This ability to accommodate change makes modular design extremely attractive in industries or technologies with high levels of uncertainty. Market conditions can change and technologies can be difficult to master. Modular product architectures provide the firm an ability to adapt as conditions change or problems arise in a design process. Modularization's reduction in design complexity promises an enormous improvement in product, process, and organizational effectiveness.

The design process is an investment by the firm in to develop a product that creates customer value by meeting a specific customer need. Modularity can reduce the size of this investment in product realization by reducing the cost and schedule of the design process. However, modularity's greatest improvement of the firm's return on investment is not reduced cost in meeting this specific customer need, but the creation of other attractive real options (Carliss, Baldwin, and Clark, 2003). Modularity facilitates design reuse and minimizes the cost of design change, which enables the establishment of product platforms. Product platforms are reusable module designs that can meet the needs of multiple customer groups.

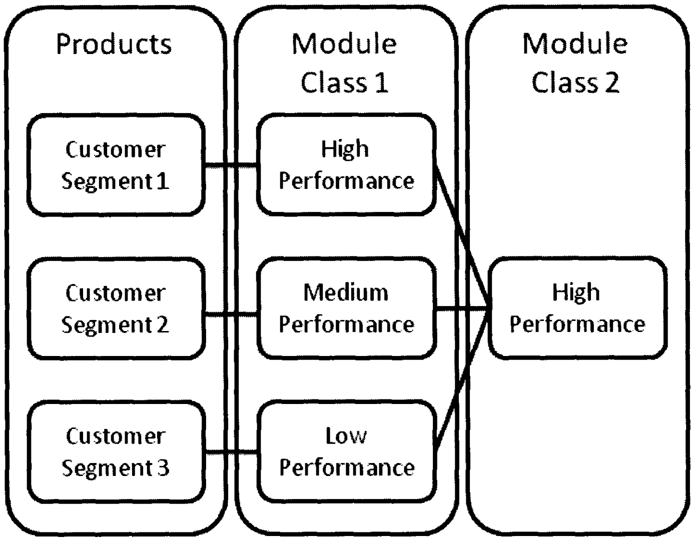


Figure 12: Reuse of Modules to Establish Product Platforms

For example, Ford may utilize the same modular drive train in several automobiles which are targeted towards distinct customer segments. The use of common design platforms reduces the design cost and time to market for products that utilize the product platform. As long as customer and firm requirements stay within the real options presented by the product platform, modular architectures facilitate rapid response to a larger variety of customer needs.

2.5. Capabilities Required by Modular Design

In order to successfully create a modular architecture and leverage product platforms, several organizational capabilities are required:

- Creating effective modularization strategies
- Continuous management of the modularization Design Rules
- Leadership with greater depth of architectural knowledge
- Identification of the driving forces of integrality
- Architecture validation and performance evaluation
- Interface management

Modularization of a product's architecture alone will not guarantee to facilitate all of the potential modularity-enabled benefits. These benefits must be specified as requirements early in conceptual design to ensure that the process and organization also support their realization. For example, enabling concurrent design requires both modular product architecture and an organizational ability to split design resources, such as personnel or test equipment. The ability to articulate how product modularity will be leveraged and define program management strategies to realize these goals are required capabilities before modularization can benefit the firm.

The establishment and management of modularization Design Rules is an essential organizational capability that is typically poorly implemented. Often, modularity is added to the design process as simply another design requirement and the design process is expected to proceed as any other project. However, the benefits of modular design do not come without significant investment by the firm. Effective product modularization requires a completely new approach to early stages of the design process. Collecting all of the required design information and establishing the modularization plan can significantly increase the level of effort required in conceptual design. New design process, information systems, and patterns of communication must be developed in order to successfully create modular architectures and leverage product platforms.

Very different design management capabilities are required to manage the design of integral product as compared to modular products. Integral products are comprised of chunks, rather than modules, which can have several visible and hidden dependencies between chunks. Additionally, the allocation of system functions and behaviors can be spread across several chunks. In integral product design, very high level system requirements are flowed down to chunk design teams who are required to manage these interactions between their individual chunks, the rest of the system, and its operating environment. Chunk design teams are required to be multi-disciplinary in order to identify and manage all of the unidentified design dependencies from the various domains. As the design process progresses, chunk design teams engage in frequent unstructured design dialogue to resolve undesired system behaviors or chunk interactions and monitor system-level performance. Design leadership plays a system integrator role by facilitating this unstructured interaction between teams. Additionally, since design of chunks is inherently complex, design leadership for integral products specialize in mitigating complexity from other non-design domains, such as organizational and processes. Therefore, integral product leadership tends to be of managerial backgrounds rather than design experts.

Modular product leadership tends to require much greater product knowledge depth from program management, especially at the early stages of design. Leadership of modular design teams must facilitate the establishment of the modularization strategy and Design Rules which can require an enormous quantity of architectural knowledge. As the design organization of modular products tend to modularize around architectural lines, these module design teams interact infrequently and with highly structured dialogue. This reduces the need for leadership to facilitate design team communication.

However, it is unlikely that all architectural dependencies were identified during conceptual design. Many architectural dependencies such as mechanical and power connections are obvious and immediately visible to even the casual observer. Many system behaviors, such as aerodynamic properties, electromagnetic radiation, and vibration, are very difficult to identify and to manage. Unfortunately, these system behaviors are often key system properties for Aerospace products. After the establishment of the Design Rules, it becomes the leadership's responsibility to continually identify these hidden dependencies and revalidate the Design Rules as the design matures and additional system knowledge becomes available. Therefore leadership plays a system architect role when designing modular products which requires a much greater depth of knowledge in the design, production, and customer domains. Having the appropriate leadership is crucial to developing the capabilities required by modular design.

Often in mature product industries, existing integral product architectures are "modularized" without significant investment in articulating the forces driving toward integrality or identification of design dependencies in an effort to quickly leverage the promised benefits of modularization. Such "paper-modularization" may not initially adversely affect the design process since the integrative capability of the organization will mitigate hidden design dependencies as they arise. However, leveraging the modularity enabled capabilities, such as design reuse or concurrent design, will be difficult. Reusing a module that had hidden design dependencies will require much greater effort to integrate with any system that it was not specifically designed for. It will be especially difficult for any other firm to integrate the module into their products as it would likely lack the integrative capability of the original design team and the architectural knowledge required.

When transitioning from integral to modular product architectures, it is important that the organization identify its hidden dependency management capabilities. All of the tacit knowledge (skills, processes, communication patterns, etc) that allow it to successfully mitigate unwanted design behavior must be converted to explicit knowledge for inclusion in the Design Rules. Successful conversion is unlikely to occur on the first attempt at modularization. Often, all of the design parameters will not be available until the first couple generations of modular products are manufactured, fielded, and retired. Therefore, collecting this design data as it becomes available and providing it to successive system architects to achieve a truly modular architecture is important. New organizational skills, processes, and communication patterns will be required to amass this design information.

The Design Rules serve as litmus test for module designers. As long as their module designs conform to the Design Rules, then it should demonstrate the required functionality and behavior when integrated with the system. In order to provide this guarantee, the organization must have the capability to validate functional performance and behavior of conceptual system architectures. Validation of the Design Rules can come through computer models or designer experience, but it must occur before a modularization strategy is accepted. Additionally, once the Design Rules are established and the design process begun, the organization must have the capability to verify module conformance to the defined standards. New test equipment, processes, and personnel may be required to verify Design Rules conformance. Without this capability the firm will be unable to successfully leverage modular design.

Design firms are typically defined by what they design. Essentially, "you are what you build." The skills, technologies, resources, and processes required to develop technology is acquired through the development process. The organizational capability of product delivery is improved with every product generation, effectively creating design economies of scale. Modular architectures can provide much greater access to technologies and products created around the world. Often it is more financially attractive for a design team to outsource a module rather than design and produce it internally. However, this outsourcing decision can present a trade between the short-run value of reduced product cost and the long-run implications of reduced organizational capability in delivering that particular product.

The strategic sourcing of module design and production can have serious implications for the future performance of the firm, especially when reuse or establishment of product platforms is desired. Outsourcing could be damaging if the firm wishes to compete in this product space in the future. Winner and losers are created quickly in industries based on modular products.

Christenson has demonstrated how can difficult it is to establish global leadership in modular competition (Christenson, 2003). Outsourcing critical modules could mean the difference between down and out of the game. As Fine has indicated, strategic sourcing and value chain design could be the ultimate organizational core competency and source of competitive advantage (Fine, 1998).

Organizations that utilize integral architectures often have multiple interface designs, even within successive generations of the same product. Interfaces can often become system performance constraints. If interface standardization does not create organizational value through the enablement of design reuse or concurrent design, redesigning interfaces become attractive opportunities for maximizing system performance. Therefore, organizations that build integral product architectures rarely develop effective interface management capabilities.

However, the ability of the firm to leverage many of the benefits of modular design is dependent on effective interface management. A product's interfaces become more than a physical method inter-module communication within the design firm. Product interfaces structure dialogue between design teams, affects the architect's ability to leverage internal and external sources of technology, and determines the number of participants in the value chain. Effective management of interfaces requires several organizational capabilities. The firm must be able to standardize internal product interfaces to maximize the opportunities of design reuse and facilitate the decoupling of design efforts. It must specify stable product interfaces for suppliers to minimize complexity of the design process. Additionally, it must maintain control of its interfaces in the marketplace through participation in industry standards bodies or fighting standards wars with competitors. All of these capabilities require recognition of the value of interfaces to the firm and an investment in managing and protecting these interfaces.

2.6. Modular Production and Usage

Many of the benefits of modularity are found outside design process improvement. Modular product architectures also facilitate modular production and modular use. Modular production leverages the modularity of the product to provide the firm access to additional sources of scale and scope and reduce production complexity. For example, the modularity of modern commuter planes enables Boeing to centralize production of components, such as wings, within one facility and capture economies of scale and quality improvements. Modularity also allows Boeing to gain access to world class capabilities that exist outside the firm. Standardization and well-managed interfaces allow Boeing to utilize jet engines from General Electric that are more affordable and reliable than it could produce itself.

Benefits of Modular Production
- Economies of scale
- Economies of scope
- Reduced complexity
- Reduced integration and test effort

Effectively leveraging modular production requires several organizational capabilities. Outsourcing production without adequate modularization of the product can lead to disaster when the various components are eventually integrated together. The time and expense of integrating a complex product could outweigh the scale benefits of outsourced production. Strategic sourcing is also a key competency required in firms that wish to utilize modular production. The scope of the firm is a decision that should be made with more considerations than short term cost savings. Outsourcing reduces the firm's ability to create internal scale and obtain valuable product insight that could lead to future product improvements. Sourcing decisions should support the firm's long run strategic vision. Modular production can also require additional coordination and communication capabilities as manufacturing is decentralized or outsourced to ensure final production schedules and budgets are met. Additionally, firms require the legal rights to decentralize production. For example, AMD's x86 license contract with Intel does not allow them to export designs to other firms to manufacture, limiting their ability to match Intel's scale advantage.

Capabilities required by modular production
- Modular product architecture
- Strategic sourcing
- Additional coordination and communication
- Legal rights

Modular usage is typically what consumers refer to as product modularity. Modular products, such as computers, are user customizable and facilitate incremental upgrades or changes in configuration as needs evolve. The decoupled interfaces and standardization of battery design allow consumers to replace batteries in their electronic devices from their supplier of choice with little consideration of performance or compatibility.

Benefits of modular usage
- User customizable
- Ease of maintenance
- Incremental upgrades

Modularity of use will fail to be realized if the consumer lacks the physical ability, legal right, or knowledge required to alter the system configuration. For example, automobiles have highly modular architectures. However, few users have the capability or equipment required to replace an alternator or a transmission themselves.

Required capabilities for modular usage
- Legal and physical capability
- Appropriate system knowledge

2.7. *Definition of Openness*

Open architectures are characterized by their use of stable, widely-accepted, and non-proprietary interfaces and standards. Open architectures creates an enabling environment that provides the designer and customer access to the greatest number of design, production, and usage capabilities. The relative openness of interfaces and standards is determined by the degree to which they are available and utilized by all relevant developers. The ultimate test of product openness is: "Can a third party developer replace a system component using only openly published and available technical specifications of the component?"

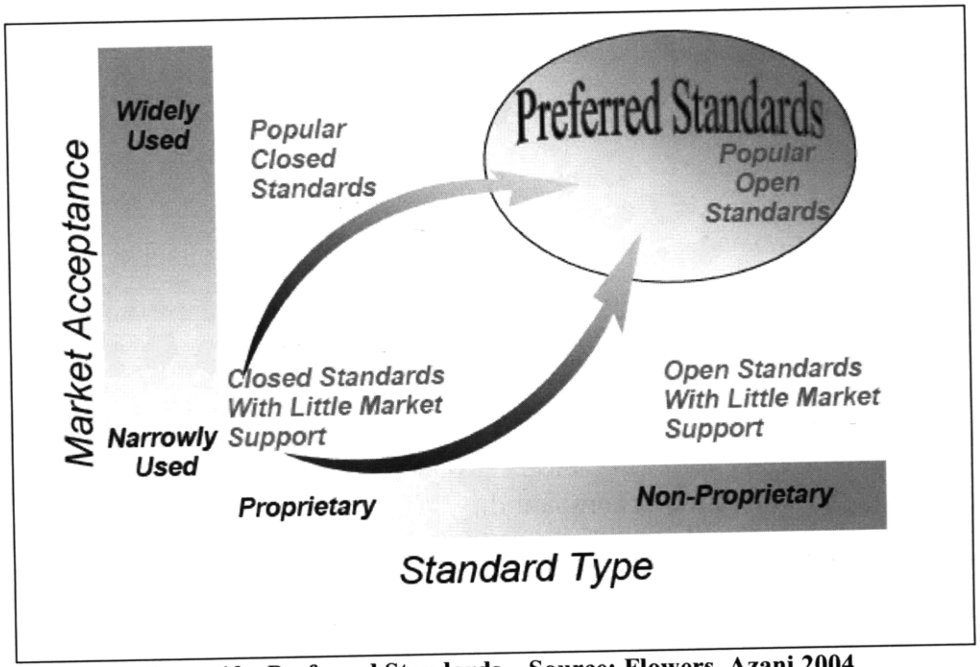


Figure 13: Preferred Standards – Source: Flowers, Azani 2004

3. Role of Product Architecture in the Firm

3.1. Co-evolution of Product and Enterprise Architectures

Enterprises are complex and dynamic systems that evolve over time as they try to align their strategy with the competitive context and the real options presented by the product. Enterprises consist of a dense and dynamic web of information, money, and resources between the various elements of the enterprise. This architecture lays the foundation upon which organizational capabilities and core competencies are based. The interactions between the products, processes, and organization are often the most direct and visible and present many of the opportunities for improving firm performance. We can analyze enterprise architectures with the same framework we used to characterize product architectures:

Physical Decomposition

- Product - sub-systems, sub-assemblies, and components
- Process – sub-processes, tasks, activities, and work units
- Organization – teams and individuals

Interfaces

- Product – patterns of interactions between components
- Process – information exchanges across the tasks in order to execute a task
- Organization – communication patterns and the chain of command

As shown in the previous chapter, Design Structure Matricies (DMSs) are used by system architects to mapping the product's physical decomposition and interfaces to identify hidden design dependencies between product modules. Eppinger, Sosa, and Rowles (2001) extended the use of DSMs to track the co-evolution of products, processes, and organizational designs and identify "misalignment" between product and enterprise architectures. They defined how new processes, product architectures, and organizational designs are created as:

1. Deficiencies are identified in the firm's ability to execute the development process and realize the product.
2. Architectural change in the product enabled new organizational forms and behaviors

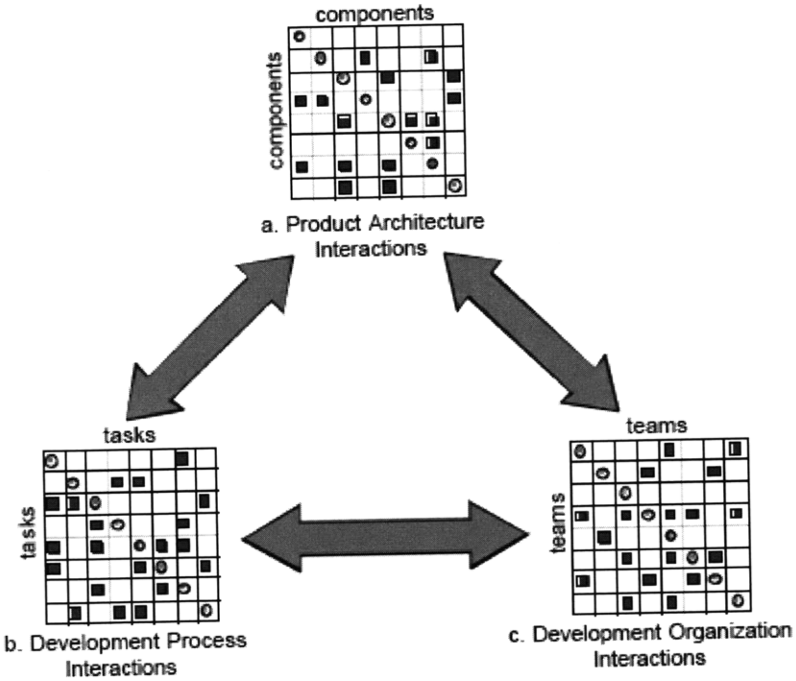


Figure 14: Three Domains of Product Development Interactions – Source: Eppinger, S. 2001

Many firms utilize product and enterprise architectural alignment to create superior organizational capabilities. Intel recognized the interdependency between manufacturing process interactions and the communication patterns of its process engineers. It famously organized the cubicles of these engineers to match the layout of the manufacturing floor to facilitate communication that resulted in improvements in manufacturing efficiency.

Often organizational complexity prevents enterprise leadership from identifying opportunities to achieve alignment and improve organizational capabilities. To facilitate alignment, Nightingale and Rhodes have provided a structured and holistic approach to evaluating all the various enterprise elements and their interactions. They note that interdependencies exist between the product and almost every element of the organizational design. Management of these interdependencies is becoming increasingly important as the growing complexity of technology products is driving up organizational design complexity and obscuring opportunities to achieve alignment.

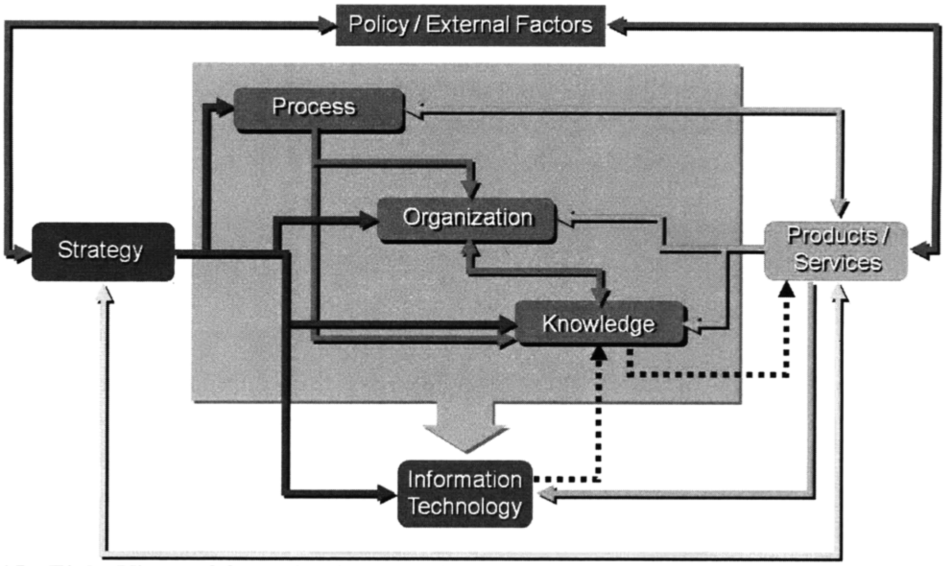


Figure 15: Eight Views of Organizational Design - Source: D. Nightingale and D.H. Rhodes, 2008

3.2. *Added Value Analysis*

As we have seen, enterprise architecture's co-evolve with its product's architecture and the competitive context. Successfully aligning the enterprise and product architectures can lead to superior operational capabilities in realizing products and services that create value for its customers. However, how do firms capture this value? More specifically, what role do product architectures play in maintaining firm profitability over the long run? In order to answer these questions we will require a framework for evaluating the competitive advantage of firms.

Many frameworks for evaluating firm performance exist. Porter's Five Forces framework is often used to examine the competitive dynamics within an industry and determine its attractiveness.

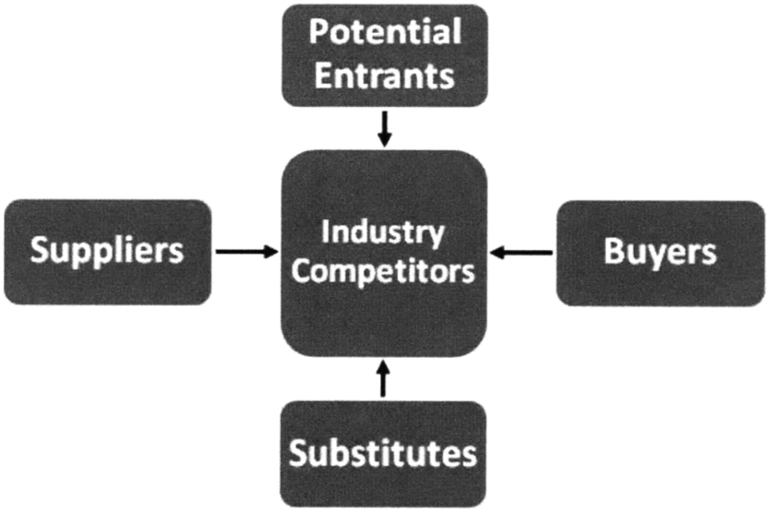


Figure 16: Porter's Five Forces Framework

However, Porter's approach provides us little guidance on evaluating the impact of evolving product architectures and the capabilities they convey to and require of the firm. Therefore, we shall utilize an added value approach to evaluating the effects of product architecture on firm performance. Added value analysis seeks to answer the following questions:

1. Who are the relevant players?
2. What value is created by these players collectively?
3. Which players are capturing this value?

We shall utilize the concept of value chains to identify the relevant players. Every industry participates in a value chain. Upstream are the suppliers that contribute to the inputs used by members of the industry; product components, labor, raw materials, or capital. Downstream are the consumers who purchase the products and services of firms in the industry. The value chain is the entire network, from raw materials to final consumers, where each member contributes some value to the chain.

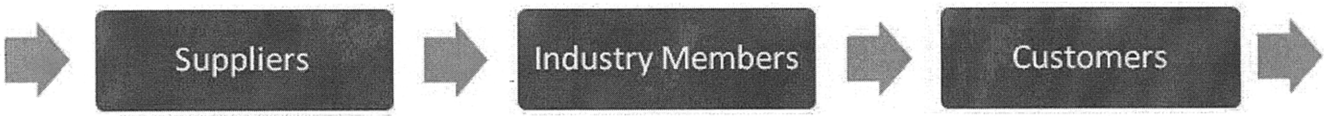


Figure 17: Sample Value Chain

While every member of the chain contributes value to its inputs and this value is divided among the participants in the chain, individual members are not guaranteed to capture any of their added value. In order to explain firm performance, it is critical to identify both how value is created and captured. A firm's value creation can be thought of as the difference between the customer's Willingness-to-pay (WTP) for its products and the negotiated cost of its inputs.

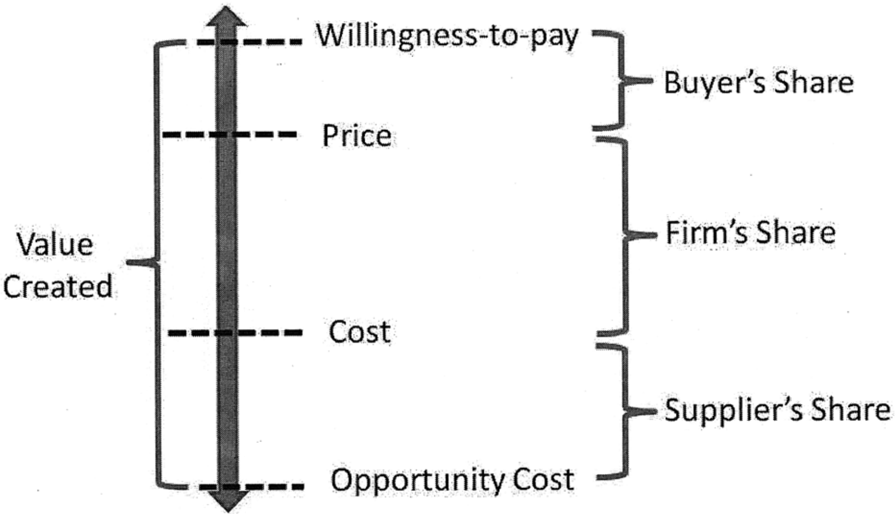


Figure 18: Creating and Capturing the Pie

A firm's ability to both maximize the value it creates and extract this value from its value chain is its competitive advantage. As the name implies, competitive advantage conveys advantage to the firm over its rivals. Without competitive advantage, its suppliers and customers would find another intermediary in the marketplace that would allow them to capture more of the value created by the value chain. Sources of competitive advantage may be shared among firms, but unique sources of competitive advantage are the most valuable.

There are two sources of competitive advantage; capabilities and positions. Firm capabilities are its ability to create added value for the value chain. Examples of firm capabilities include Toyota's low cost, high quality manufacturing capability and Apple's ability to design customer pleasing consumer electronics. While these capabilities have been particularly difficult for their competitors to replicate and have conveyed them a sustainable competitive advantage, not all firm capabilities are sources of competitive advantage. Only capabilities that contribute to a firm's ability to profit are sources of competitive advantage. Note that other firms might also have similar capabilities and therefore conferring you no competitive advantage, commoditizing your capabilities. In unrestricted competition between members of the industry, firm capabilities and inter-firm negotiation would completely explain firm performance. As predicted in supply and demand analysis, a zero profit condition would result if many homogeneous firms with commoditized capabilities competed in perfectly competitive markets.

However, rarely are markets completely unrestricted. Typically there are frictions that constrain interactions between participants in the value chain and allow some firms to capture more than their added value even if their capabilities are not distinctive. Positions are these non-market forces that restrict competition. Examples of firm positions include brands, laws, access to unique assets, and geographic position. Note that many positions have significant first mover advantages. However, these positions may be short lived as the rules of competition can change and competitors look for ways to overtake these frictions. It is often unwise to entirely establish a firm's strategy for sustainable competitive advantage on positions due to their fleeting nature.

3.3. Architectural Change and Competitive Advantage

In the previous sections, we have identified how product and enterprise architectures co-evolve as:

1. Deficiencies are identified in the firm's ability to execute the development process and realize the product
2. Architectural change in the product enabled new organizational forms and behaviors

The improvements in organizational capabilities and creation of new real options resulting from changes in product architectures have significant impacts on a firm's ability to create sustainable competitive advantage. This co-evolution of product architectures and the way firms compete has been no more visible than in the evolution of information technology. We will utilize the presented framework to evaluate the impact that evolving product architectures had on IBM, a key player in IT.

Mainframe-Era IBM

During the mainframe era, IBM was the information technology industry. It essentially captured all of the value created by IT at the time. IBM's value chain consisted primarily of small subsystem and component suppliers and large institutional customers such as governments, schools, and corporate IT departments. Due to the relative immaturity of computing technology in this era, few organizations could articulate their individual computing needs. IBM technically knowledgeable sales force would work with these customers in order to translate these needs into technical requirements for its products. IBM then could match their customer's computing needs with highly complex mainframes composed of components sourced from its many suppliers.

This customer and product complexity presented a significant barrier to entry to potential competitors. Mainframes are large and highly complex systems. The architectural knowledge required to design a mainframe's subsystem was enormous. Obtaining the required technical capabilities and realizing the economies of learning required to competitively supply components to IBM's customers was nearly impossible. IBM utilized a proprietary instruction set and operating system and patented many of its interfaces creating legal barriers to market entry. IBM was able to use modular mainframe components to create significant economies of scale in production. Much of IBM's added value arose from its capabilities in managing complexity and efficiency realizing the product.

IBM's success eventually made IBM synonymous with computers and "Big Blue" enjoyed strong brand power amongst its customers. These capabilities and positions provided IBM strong control of its value chain. IBM could compete suppliers of components amongst each other, driving down its costs, and extract much of the value created by IT out of its customers.

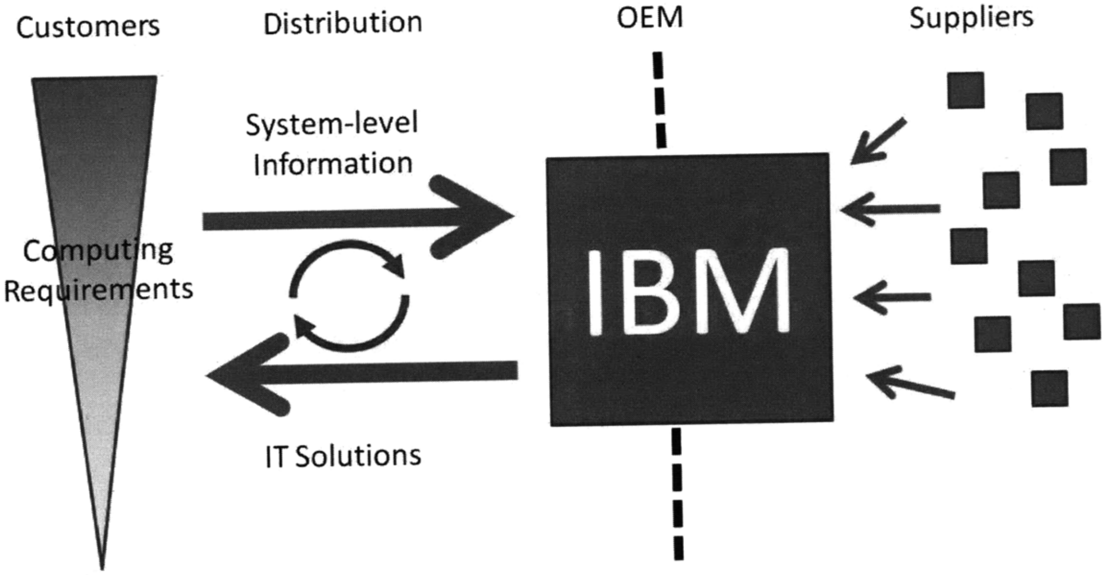


Figure 19: IBM's Mainframe-Era Value Chain - Source: Fine, C 2004

Sources of IBM's Mainframe-era competitive advantage:

IBM's Capabilities:

- Understanding of a customer's specific computing requirements
- Ability to manage architectural complexity
- Product realization efficiency
- Integrative capabilities
- Relevant technology competencies

IBM's Positions:

- Brand
- Proprietary interfaces
- Strong relationships with customers with rich technical dialogue

The IBM 360

IBM designed the IBM 360 to deliver the affordability required to meet smaller markets that were inaccessible with its large mainframe products. Mainframes components, while modular in production, were only modular in use within one product line. The 360 was conceived as a family of computers that were of different sizes suitable for different applications. 360s utilized the same instruction set and standardized interfaces, meaning that programs and peripherals developed for the 360 would be compatible for nearly every system configuration. The 360's additional modularity in design, production, and usage created economies of scale and learning and make computing much more affordable for a new market of customers.

In order to ensure that these modular production and usage capabilities were realized, IBM modularized its design organization to match the product architecture of the 360 and highlight potentially hidden dependencies between modules. It created a centralized design rules team that developed the modularization strategy and decentralized development teams that were responsible for each of the modules. This organizational design enabled IBM to identify hidden design dependencies and create an effective modularization strategy. IBM organizational strategy was essential in achieving its goals delivering modularity in design, production, and use capabilities.

IBM successfully captured a large portion of this new market created by the IBM 360 for years. However, the enormous size of IBM's value chain made it extremely attractive to its competitors. The modular architecture of the IBM 360 enabled competitors to eventually reverse engineer the 360's interfaces and offer plug-compatible components. Patenting the 360's interfaces and threats of legal action were unable to deter competitors from picking pieces of the value chain away from IBM. However, for the most part IBM was able to dominate the industry with successive generations of the IBM 360 that were continuously one step ahead of the clone makers in performance. The presence of these competitors, while extracting some value from the 360, actually added enormous value to the platform by supplying additional complements that provided IBM competitive advantage in competing with other mini-computer manufacturers.

The relationship IBM had with its customers was significantly altered by the modular architecture of the IBM 360. The scalability of IBM 360 allowed many customers to match their needs to a specific technical solution. Institutional IT departments could roughly estimate the IBM 360 model that would meet their computing requirements and no longer required the assistance that IBM's technically-oriented sales force could provide. While IBM maintained strong relationships with the institutions it had worked with for years and continued to provide the most demanding customers unique technical solutions, the rich technical exchange that provided IBM such a strong competitive advantage began to fade.

Sources of IBM's competitive advantage:

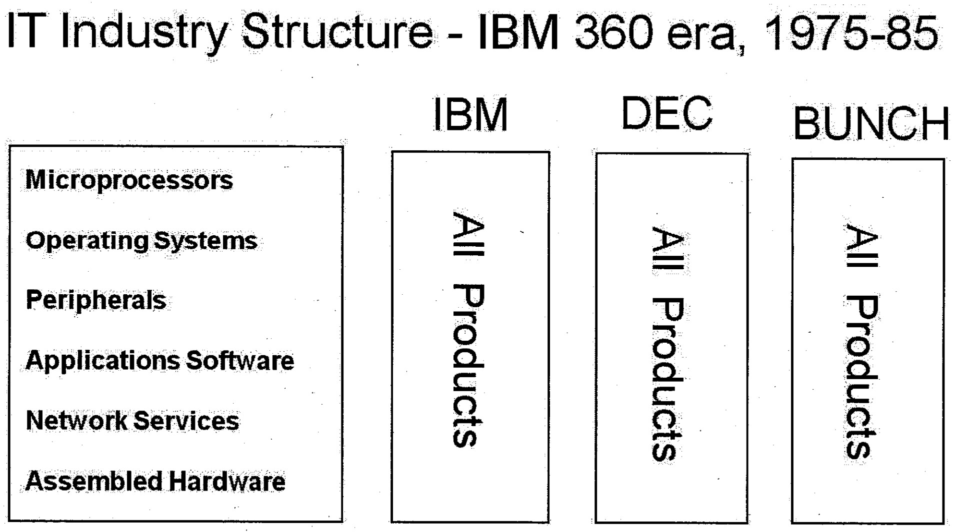
IBM's Capabilities:

- Ability to manage architectural complexity
- Product realization efficiency
- Relevant technology competencies

IBM's Positions:

- Brand
- Proprietary interfaces
- Strong customer relationships
- Platform leader

IBM maintained an integrated vertical structure as product complexity, architectural coupling, and Intellectual Property provided it strong sources of competitive advantage and value chain control.



(A. Grove, Intel; and Farrell, Hunter & Saloner, Stanford)

Figure 20: Vertical Industry Structure with Integrated Product - Source: Fine C., 2004

PC-era IBM

In 1982 millions of home computer models were being sold by firms such as Apple, Texas Instruments, and Commodore, Atari. IBM feared that they were missing out on this exciting new market segment and were losing relevance in the computer industry. In order to quickly establish a leadership position in the already crowded home computer market, IBM created a special team thousands of miles from its corporate headquarters with full authority to cut through any organizational red tape that would hinder the delivery of the Personal Computer (PC). This decision to free the design team from the needs of the enterprise had significant impacts on the future of IBM.

The team's primary requirement for the architecture of the Personal Computer was the quick delivery of an affordable and open platform that would be attractive to developers. Little consideration was paid to how IBM would sustainably capture value from this platform. IBM's ability to out-innovate its competitors and leverage its position at "Big Blue" enabled it to dominate the industry in previous product generations and was assumed to continue into this new era. Patenting the ROM BIOS was its only source of platform control the team installed in the architecture of the PC. However, the team decided to publish the complete PC ROM BIOS in IBM's technical reference manuals to aid application developers.

The team's focus on quick delivery and affordability meant that it made two decisions that had drastic implications for the future of IBM. During negotiations with Microsoft on the licensing terms for DOS, they allowed Microsoft to freely license it to competitors in exchange for a lower flat rate for DOS. Microsoft was now strongly incentivized to facilitate not only IBM's market success, but clone manufacturers as well.

IBM had the 801 processor available for the PC team. It was a powerful chip for its time and had an advanced operating system already developed for it. However, the 801 would come with organizational red tape which could slow the delivery schedule for the PC and limit the freedom provided the team. So Intel's 8088 processor was selected for the PC even though it was significantly less powerful than the 801. It was inexpensive, IBM already had a product based upon the chip, and there was an existing developer community already familiar with the design. The 8088 met the speed to market and affordability requirements of the design team. However, this decision may have had a profoundly negative effect on the future of IBM.

Disruption of IBM

Facilitated by the availability of the ROM BIOS source code, many companies quickly went to work reverse engineering the architecture of the PC and providing cloned products. A short ten months after IBM launched the PC, Columbia Data Products had copied the design and was selling PC-compatible machines. Many other manufacturers followed closely behind. IBM kept improving the PC with larger storage capacities, faster processors from Intel, and updated versions of DOS. However, each of these incremental improvements was available to and quickly adopted by its competitors. It would improve the layout of components and introduce new interfaces, but these were imitated or reverse engineered. While IBM developed a large array of applications and peripherals for the PC, the market quickly became highly competitive as an enormous industry of small suppliers with similar offerings sprung up around IBM.

IBM's brand, strong customer relationships, and a reputation as a leader in its industry initially provided it a significant competitive advantage with its big institutional customers. Many generations of IBM PCs were popular within these segments. However, as other clone manufacturers established themselves in the market, these positions began to fade. The majority of IT customers could meet all of their computing needs with the real options presented by the PC, and few customers required unique computing solutions that warranted IBM's technical expertise. The important performance and technical specifications for a PC could be summarized on the side of a cardboard box of software. IBM's institutional customers could identify exactly the computing hardware they needed without the help of IBM's sales force and could compare IBM's products objectively with their competitors over a small and standardized set of features. IBM lost the rich technical dialogue and close relationships that it once had with its customers.

The way in which IT customers valued their PC suppliers changed as well. The performance and capabilities of PCs quickly became commoditized. Maintaining compatibility with current and future architectural standards became the driving incentive for customers which greatly slowed architectural change. The small number of customer-valued performance specifications and the universal availability of incremental improvements meant that PC suppliers were largely competed on total cost of ownership alone. A supplier's ability to efficiently deliver the customized IT solutions eventually became the only source of competitive advantage among PC vendors. IBM's value chain and its customer-valued capabilities had changed significantly from its mainframe-era:

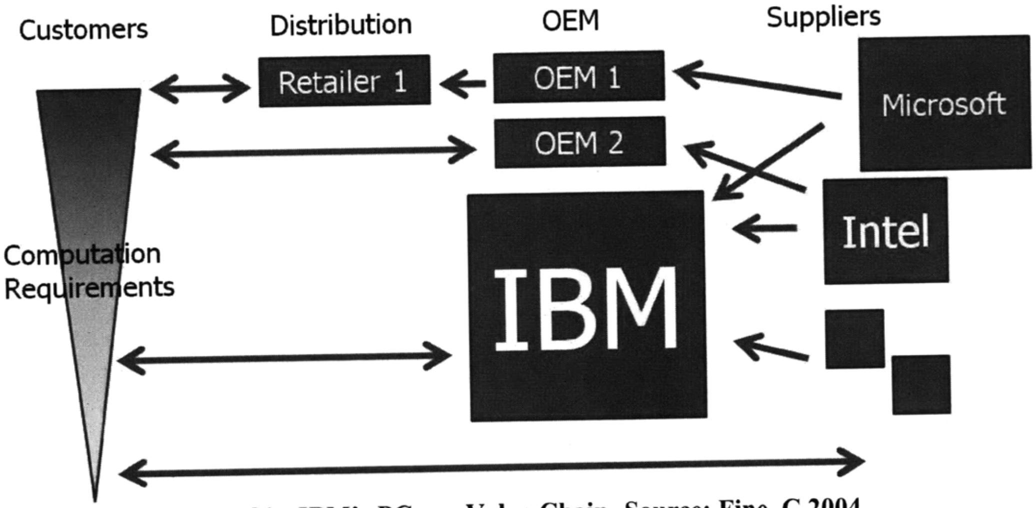


Figure 21: IBM's PC-era Value Chain- Source: Fine, C 2004

Sources of IBM's competitive advantage:

IBM's Capabilities:

- Product realization efficiency

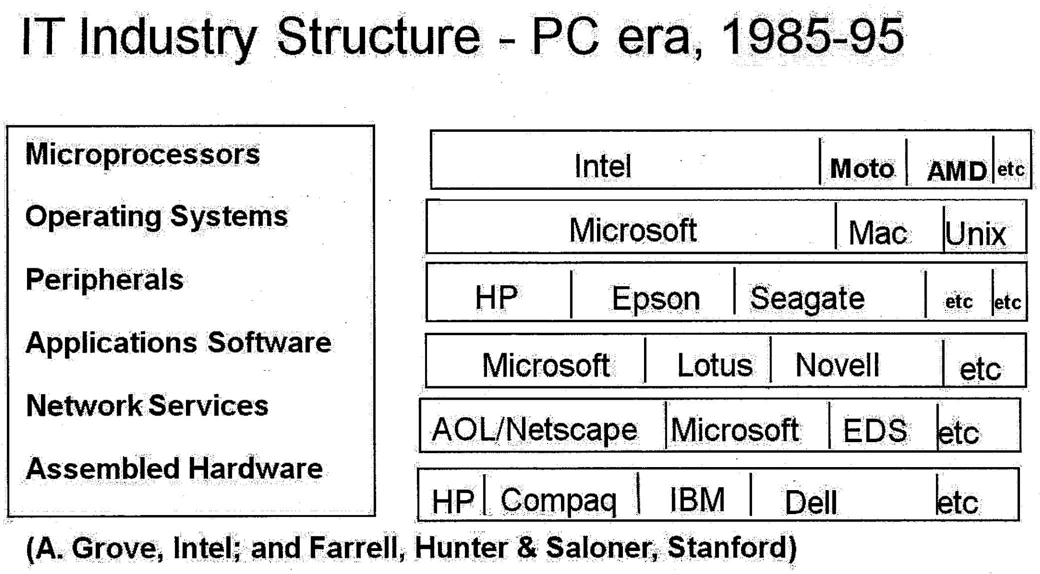
IBM's control over the platform and the popularity of their products faded with every generation of the PC. While IBM maintained significant technical expertise and market leadership in PC components such as hard drives, its industry position was mostly of an integrator / OEM role. Unfortunately, IBM lacked any distinctive low-cost manufacturing, delivery, and customer support capabilities that would provide them competitive advantage in integration. IBM's inability to create these organizational capabilities relegated it to ever-declining market shares as a PC integrator.

Firms like Dell sprung up to attack IBM head on. Dell created an entire organization oriented towards delivering customized PC products quickly and cheaply. Dell's strategy was to affordably deliver highly customized products to knowledgeable "have it your way" markets such as corporate IT departments and discerning home users. By aligning the enterprise architecture with this strategy, Dell developed "internal consistency" that allowed it to develop distinctive manufacturing, delivery, and support, capabilities that provided it competitive advantage as a system integrator.

Figure 22: Internal Consistency of Dell's Organizational Design

Microsoft and Intel held the only unique components that delivered value for the majority of PC customers. After the release of the Intel 286 processor in 1986, Intel and Microsoft largely controlled the PC architecture and captured a significant portion of the value from IT. While many firms entered the industry with popular products and services that briefly established them as a force in the industry, few firms other than Microsoft and Intel were able to create distinctive positions and capabilities that have provided them sustainable competitive advantage in the PC era. Intel's scale and scope advantages allowed it to heavily invest in R&D for its x86 line of processors, leading to exponential improvements in speed and besting their competitors. Microsoft, benefited by the network-effects of OS and file-type standards, has been able to maintain its market dominance over other alternatives.

The industry rewarded firms, such as Dell, Intel, and Microsoft, as their specialized capabilities or distinctive positions enabled them to capture their pieces of the IT value chain.



IT Industry Structure - PC era, 1985-95

Microprocessors	Intel	Moto	AMD	etc	
Operating Systems	Microsoft	Mac	Unix		
Peripherals	HP	Epson	Seagate	etc	etc
Applications Software	Microsoft	Lotus	Novell	etc	
Network Services	AOL/Netscape	Microsoft	EDS	etc	
Assembled Hardware	HP	Compaq	IBM	Dell	etc

(A. Grove, Intel; and Farrell, Hunter & Saloner, Stanford)

Figure 23: Horizontal Industry Structure with Modular Product - Source: Fine C., 2004

Key Points

The advent of the Personal Computer, and its standardized, modular, and open architecture, led to the erosion of IBM's competitive advantage over time and its eventual exit from consumer IT. The architectural disruption of IBM has provided much insight to the interdependencies between product architectures and organizational forms.

Key Points:

- Product architectures can have a profound effect on your customer supplier relationships and can determine who captures the value created by your product
- Network effects of standardization limit the opportunities of firms to profit from architectural innovation
- Large activity networks can commoditize even difficult to create knowledge assets
- Standardized modular and open product architectures enable suppliers and customers to meet up in the marketplace without the architect. Inventing the platform is not enough to maintain thought leadership within the industry and control of the platform
- Only firms with distinctive capabilities and positions created sustainable competitive advantage. Few of these exist when standardization and openness make the related capabilities available to all and minimize the opportunity to create positions.
- Large value chains with modular and open products enable and incentivize specialization
- Specialization in technological capabilities can greatly increase the rate of product improvement
- Excellence in capabilities leads to value capture only when the additional performance is valued by the customer

3.4. Cognition of Shifting Competitive Contexts

When faced with possibly disruptive changes in product architectures, it is imperative that the firm have the following organizational capabilities in order to minimize the effects of disruption:

- Understanding of its value chain and its position within it
- Clear articulation of how the firm creates competitive advantage over its rivals
- Recognition of how a change in competitive context impacts the value chain and its ability to create competitive advantage
- Definition of a successful strategy in this new competitive context
- Ability to align the firm with the strategy

Path dependencies often determine a firm's ability to identify, commit, and create the organizational capabilities required to compete in a new competitive context. For example, firms in industries that undergo high rates of change and are routinely faced with potentially disruptive threats, such as technology-oriented firms, typically have strong organizational capabilities in perceiving shifts in their competitive context and creating and implementing strategy.

However, path dependencies can have negative effects on successful firms in mature and stable industries. As products and value chains stabilize, the competitive formula of a firm can become embedded in the enterprise architecture of the firm. As a firm seeks to align its enterprise architecture with its strategy for creating and capturing value, over time its competitive formula can become embedded in everything from incentive structures and cultural beliefs to design processes. Eventually the competitive formula can become so pervasive and unchanging that it is no longer managed explicitly and is converted completely into tacit organizational knowledge. Teece noted that mature firms in stable industries may eventually be unable to define how exactly it is able to create the organizational capabilities that provide it competitive advantage. This "causal ambiguity" can sometimes even serve as a source of competitive advantage as it makes replication of these capabilities by potential competitors difficult.

While embedding the competitive formula in the organizational architecture may improve firm performance during times of stability, these beliefs, information filters, processes, and organizational designs may become "strategic straightjackets" when disruptive changes occurs. If strategy and organizational design are not managed explicitly, it becomes exceedingly difficult for a firm to identify when a change in strategy is required. Even if management recognized a shift in the competitive context, an entrenched competitive formula creates organizational inertia that can prevent management from aligning the firm with a new strategy.

The disruption of Polaroid is an excellent example of a successful firm that was disrupted by organizational inertia. Despite early investment and leading-edge technical capability in areas related to digital imaging, Polaroid could not survive in the digital photography era. Polaroid's 40 year history of effectively competing in the photography industry was embedded into the beliefs of its management. These beliefs prevented Polaroid from identifying and creating the required organizational capabilities when faced with disruptive product change.

Polaroid's Beliefs:

- Customers want instant physical prints with "photographic" quality
- Polaroid competes within the photography industry
- Polaroid is an innovator, not a "down and dirty" low cost manufacturer
- Products must sell consumables – razor / blade business model
- Successful products earn >65% profit margins

These beliefs combined with consistent film sales prevented Polaroid's management from taking digital photograph seriously. They could not rationalize committing to digital photography when their current film photography products offered improved image quality, instant physical prints, and much higher profits than digital photography products. The beliefs and experience of Polaroid's management prevented them from recognizing:

1. Possibility for rapid improvement in digital picture quality
2. Customer's value for eliminating consumables and the usage possibilities enabled by digital photography
3. New customer markets available to digital photography products

While Polaroid Digital's PDC-2000 digital camera was developed and ready for release in 1992, a combination of internal resistance and lack of commitment to this new market prevented the PDC-2000's release until 1996. Even with its four year delay, the PDC-2000 was able to win "Product of the Year" awards due to its sophisticated design. Polaroid clearly demonstrated a leading-edge technological capability in digital photography. Unfortunately, its technology competency was not enough to prevent Polaroid's demise.

Polaroid management's beliefs prevented it from identifying and creating the organizational capabilities required competing in the digital photography market. The required technology competencies were available in many other activity networks, such as the information technology industry. Polaroid did not predict firms such Apple, Hewlett Packard, and Microsoft would enter digital photography or the effects that their entrance would have on the marketplace. The IT industry moves at what Fine calls a "high clockspeed." The IT industry experiences high rates of innovation and these companies have the rapid product development and low cost manufacturing capabilities required to compete and profit in these "high clockspeed" environments. Polaroid never developed these organizational capabilities as they were not needed in 40 years of competing in the film photography industry. These IT industry firms were able to drive in rapid improvement of performance and affordability of digital camera products. Polaroid's management again hesitated to invest in creating these capabilities due to distaste for competing in such a highly competitive marketplace. Polaroid's inability to keep up with the high rate of innovation and competitive pressure found in the newly defined digital photography industry prevented them from competing effectively.

When faced with disruptive technology change, Polaroid's beliefs prevented management from:

- Reevaluating their value chain
    - Who are their customers and how they value, purchase, and use the new product
    - Who are their competitors and suppliers
- Correctly identifying an effective strategy for this new era
- Overcoming organizational inertia and committing to the new strategy

4. DoD's MOSA Procurement Strategy:

[Long-term relationships with industry] "need to be based on performance and value-added, not based on barriers to entry that are artificially established to minimize competition in the long run."

- *U.S. Navy Secretary Donald Winder 11-18-2008*

4.1. Objectives

The U.S. Department of Defense has three primary objectives for their Modular Open System Architecture strategy:

Objective 1 - Rapidly and efficiently create new warfighting capabilities

The DoD has identified product complexity, changing system requirements, and variable funding levels as root causes of poor program performance. Modular designs directly address these root causes of poor program performance by accommodating uncertainty and reducing design risk. Additionally, contractors may leverage the many benefits of modular design to improve acquisition program performance. Concurrent engineering would greatly reduce the time required to complete the design. The creation of product platforms would enable suppliers to meet the DoD's needs will little to no investment in development. Standardized and open interfaces also improve system interoperability, extensibility, reusability, and maintainability. Product modularity may even enable Aerospace to increase the rate of product innovation through the utilization of skill specialization and rapid experimentation. The DoD's MOSA strategy has the potential to greatly improve its ability to create new warfighting capabilities.

Objective 2 - Provide access to world class design, production, operation and support capabilities

Due to the complexity of the technology required and the procurement environment, the DoD is currently limited in where it sources its warfighting capabilities. The DoD lacks the systems engineering capability required to identify optimal system architectures that meet its needs. Additionally, few companies outside of Aerospace have the organizational capability to manage the complexity induced by the Federal Acquisition Requirements (FAR) or provide the secrecy the DoD requires. Its inability to manage product complexity and the complexity of the procurement process has essentially tied the DoD to Aerospace contractors.

Establishing standardized modular system architectures greatly reduces the complexity of identifying optimal product configurations and would enable the DoD to drive the design process. Additionally, modularity and openness would allow it to source the system modules from firms that lack the ability to provide security. Simply defining the interface and functional specifications of modules while providing few details of the rest of the system could provide the DoD the secrecy it desires while greatly expanding its sourcing options.

However, standardized architectures do not exist for new warfighting capabilities and the DoD must rely on Aerospace firms who have the capability to manage technology complexity, are familiar with the DoD's product procurement and usage environment, and provide secrecy. This position provides them significant competitive advantages as system architects and prime integrators. These firms wish to capture as much value from design programs as possible by supplying all of the design, production, and support services related to the program. Over the course of the design process, the system architect builds additional positions that provide it competitive advantages in capturing the rest of the value chain.

Product complexity and architectural coupling provide the architecting firm strong control of the program's value chain. As the DoD lacks the technology capabilities to drive the design process, it relies heavily on the architecting firm to select hardware and services to use in the product. Strong inter-architectural coupling also limits the selection of hardware and software, often to products supplied by the architecting firm. This monopolization of architectural information and architectural coupling severely limits the DoD's ability to drive make/buy decisions and put the architect in a position of selecting only products supplied by its firm. These positions also provide the design firm competitive advantage in later production, support, and upgrade contracts as well. The use of modular and open product architectures should reduce the prime contractor's ability to establish these positions during the design process and monopolizing the value chain. MOSA will enable the DoD to utilize world class design, production, and support services, regardless if they are present in Aerospace or not.

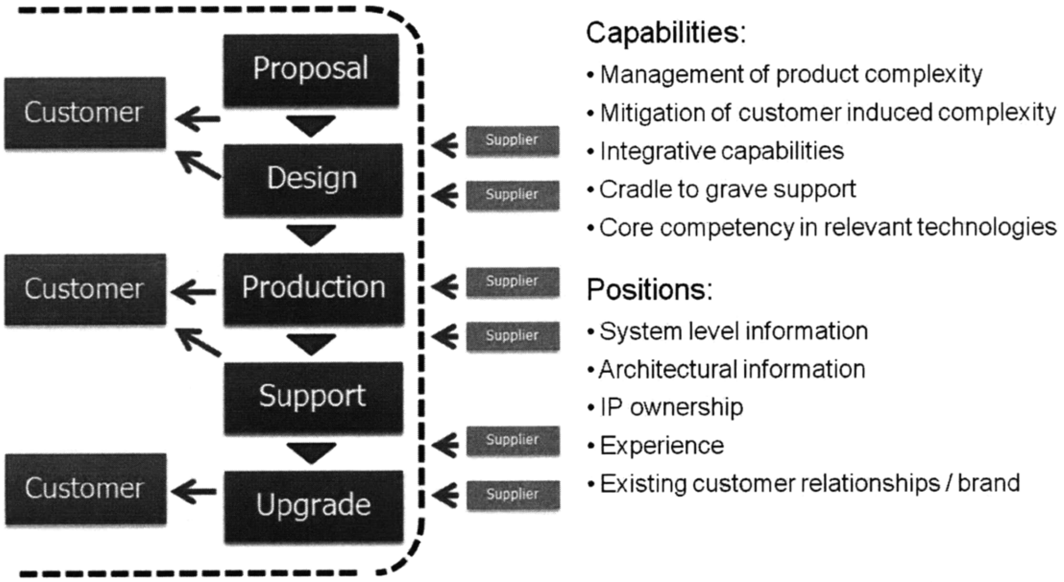


Figure 24: Product Complexity, Architectural Coupling, and Intellectual Property Provide Aerospace Strong Value Chain Control

While the DoD pays its contractors to develop cutting edge technology on its acquisition programs, Intellectual Property claims often prevent it from leveraging this technology again on other programs. The DoD often has to re-invent technology or design systems without access to technology it paid to develop. The DoD plans to minimize the use of contractor owned intellectual property on its systems and more effectively manage the IP it already owns to ensure every program has access to the most advanced technology available.

Objective 3 - Inject additional competitive pressure into the procurement process

Inter-contractor competitive pressure is main tool the DoD has to incentivize desired behavior on acquisition programs. Standardized modular and open system architectures will provide more firms the architectural information required to compete for procurement contracts. Standardization will create the scale to incentivize firms from close activity networks to compete for procurement contracts. The elimination of positions such as monopolization of product information, architectural complexity, and IP ownership should prevent the prime contractor from creating barriers to competition during the design process. Additionally, the presence of standardized architectures will commoditize many of the unique technology capabilities currently found in Aerospace. Without distinctive intellectual property or technology competencies it will be very difficult for Aerospace firms to create unique sources of competitive advantage and extract value from the DoD. MOSA has the potential to greatly increase the competitive pressure in Aerospace.

4.2. Required customer capabilities

The Department of Defense requires additional procurement capabilities before it can accomplish its MOSA objectives. The primary capabilities are:

- Joint service acquisition capabilities
- Modular and open system architectures
- Effective IP management capabilities
- Socialization of MOSA strategy
- Program evaluation and enforcement capabilities

Before the DoD can accomplish its goals, it requires several joint service acquisition capabilities. Modularization and openness are strategies for leveraging economies of scale and learning. The DoD must be able to identify opportunities to create scale between its various services and acquisition programs by identifying similar warfighting needs that could likely be met with one standardized modular product architecture. It must also build the capabilities to communicate, collaborate, and coordinate between acquisition programs to manage cross development and production activities. Joint acquisition programs, such as the Joint Strike Fighter program, are going a long way in facilitating inter-service procurement capabilities. However, the organizational cultures of the services make such collaboration difficult. The services often push development towards designs tailored to their unique usage environments. Additionally, the DoD currently lacks the systems engineering capability required to drive the scale identification process.

In order to gain many of the promised benefits of MOSA, the DoD requires a standardized modular and open system architecture. It will take some time to develop these architectures. As indicated by the previous sections, an effectively modular architecture that delivered the desired modularity of design, production, and usage capabilities would require a significant financial investment by the DoD. Also, few systems provide the opportunities to create scale that would make such investment economically viable. Yet, the DoD is currently funding several programs, such as the Radar Open System Architecture 2 (ROSA 2) program at the Lincoln lab, to create these standardized modular and open architectures.

The DoD also must improve its effectiveness in managing the IP it has developed on its many technology acquisition programs. As the DoD lacks effective inter-program communication capabilities, it frequently pays contractors to develop technologies similar to what it already owns. It must also be able to transfer the IP from one program to another supplier in order benefit from economies of learning. The DoD is currently developing IP sharing capabilities with systems such as the Navy SHARE system. These systems will help the DoD to accomplish its MOSA goals, but will take some time to become adopted by the acquisition community.

The DoD's acquisition community is enormous and fragmented between services and technology types and often operates without centralized control. Educating the acquisition community on the DoD's MOSA strategy and coordinating procurement will be challenging. While the DoD 5000.2 procurement guidelines have been updated to reflect its desire to procure modular and open weapon systems, it provides little guidance on how to evaluate weapon systems or incentivize contractors to comply. It will take some time for the acquisition community to develop the capability to evaluate a supplier's product architecture for MOSA compliance. The DoD will go through several generations of products that are advertised as MOSA compliant, yet fail to deliver the desired modular design, production, and usage capabilities. The acquisition community will require additional program evaluation and enforcement capabilities before MOSA will be effectively implemented.

While the original MOSA strategy was developed in the mid-1990s, it is only recently that proposals have contained strong-MOSA language. Fully socializing the strategy within the procurement community and developing the capabilities required to implement the strategy will take some time and a sizeable financial investment by the DoD. However, the DoD has committed to developing these capabilities and Aerospace has a limited transitional period before MOSA is fully implemented.

4.3. Disruptive Nature of MOSA

Changes in products or changes in the competitive context can be disruptive to firm performance if it is unable to recognize the change and develop the organizational capabilities required to compete effectively in a new era. The DoD's MOSA strategy an embodiment of changing customer values, new customer procurement and usage capabilities, and new product architectures. Once MOSA is fully implemented, it represents an enormous change in the competitive context. However, it is an extremely subtle change to the contractors that compete in the Aerospace industry. MOSA will prove to be highly disruptive unless they anticipate the change and develop strategies and capabilities required to effectively compete in this new era.

Henderson and Clark (1990) characterized various types of product configuration changes and identified their disruptive potential for the firm. They would define the DoD's MOSA strategy are *Architectural Innovation*, which has the greatest disruptive potential for industry incumbents. Architectural innovations are changes in the product's architecture without changes to its core components. Architectural innovations are often difficult for management to recognize or predict the impact on the competitive context. This subtly also makes it difficult to overcome the organizational inertia created by the established organizational design and to create the newly required capabilities.

The maturity of the Aerospace industry and the organizational complexity of Aerospace firms make them particularly susceptible to disruption from MOSA. These firms have been the DoD's technology job shops for decades and are experts in converting the DoD's product requirements into technology solutions. Using a wide array of technology competencies and organizational capabilities, they deliver the warfighting capabilities its customer desires. In a way, MOSA is simply an additional design requirement for system modularity and openness that must be flowed into the design process. MOSA compliant products utilize the same components and capabilities as their current products and simply allocate and interface these components in a new way. Few additional organizational capabilities are required to supply the DoD MOSA compliant products. MOSA's subtle shift in the competitive context will prove to be highly disruptive in Aerospace unless contractors recognize the shifting competitive landscape and develop new sources of competitive advantage.

4.4. *Case – Modularization of Airborne Radar*

Mechanically Scanned Arrays

The evolving architecture of airborne radars highlights the impact that MOSA may have on the Aerospace industry. A product architecture that was once optimal for the contractor and evolved to a higher performing architecture that is now suboptimal for the contractor, particularly in a MOSA procurement environment. Airborne fighter radars were once mechanically scanned, such as the APG-76 (see below), and were highly complex integrated systems. The architecture of these systems comprised of several large subsystems.

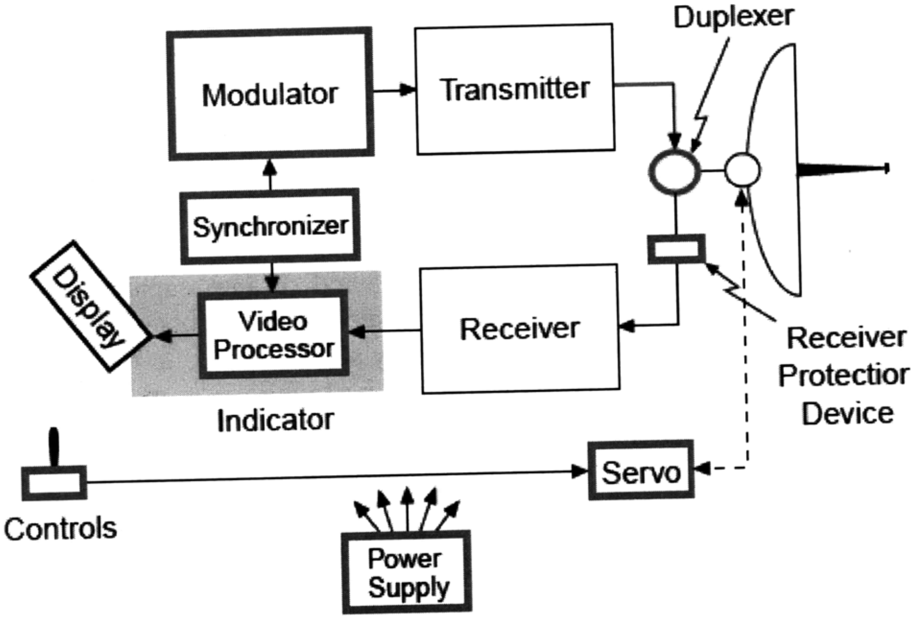


Figure 25: Mechanically Scanned Radar Architecture - Stimson, G. 1998

- Transmitter - generates the high power RF signal
- Waveguide – channels the transmitters energy to the antenna
- Duplexer – alternates access to the antenna between the receiver and transmitter
- Receiver – detects RF signals from the antenna
- Synchronizer – coordinates the operation of the transmitter and receiver
- Antenna – transmits and receives the signal
- Servo – mechanically steers the antenna
- Processor – the electronic controls for the rest of the radar and processes signals detected by the receiver

While the architecture of the MSA looks to be comprised of discrete modules, the system is highly integrated by several difficult to manage system functions and behaviors. The functional allocation of transmitting and receiving signals is spread throughout the entire RF chain. The complexity in managing the flow of RF signals in MSAs created strong integrative forces in the system. Second and third order signals in RF equipment can easily become amplified within the radar and overcome the system's ability to detect real targets. It is nearly impossible to predict how two components would interact once integrated. The integration process for these systems required highly skilled technicians and expensive test equipment and ranges. Effectively managing RF signals in integration could provide enormous performance improvements to the system.

The radar's operating environment also creates strong integrative forces in the system. Fighter aircraft have tight size, weight, and power constraints which put strong limitations on the power and sensitivity of the radar's components. Additionally, fighter aircraft nosecones experience high temperature swings and lots of vibration. However, tight size and weight requirements prevent radar designers from utilizing extensive heat or vibration management technologies. The tight size, weight, and power constraints and operating environment puts a toll on the reliability of MSAs and were typically among the most frequently failing pieces of equipment on an aircraft. This conflict between radar performance and its operating environment places a premium on the ability of the system architect to manage these many interdependencies that are spread throughout the system.

The architecture of mechanically scanned radars presented several problems to their customers. Rapidly slewing the antenna required large, complex, and powerful hydraulic systems that required lots of power and induced more vibration into an already vibration-prone environment. Depending on the location of the targets, the time required to mechanically steer the antenna severely limits the number and quality of tracks provided by mechanically scanned radar. Additionally, the hydraulic system is one of many single points of failure in mechanically scanned radars and the tight size and weight constraints limit the architect's ability to include redundancy.

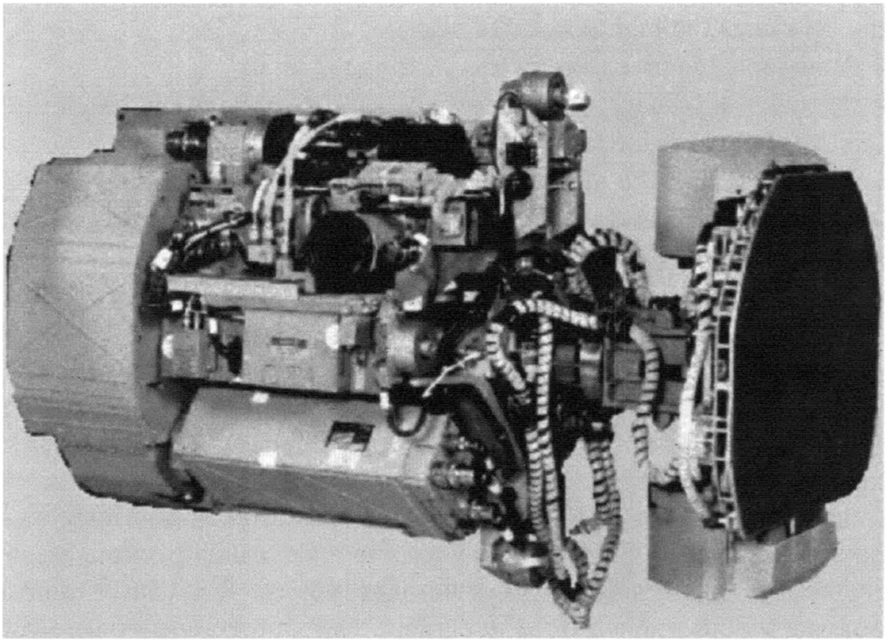


Figure 26: APG-76 Mechanically Scanned Fire Control Radar – Source: Stimson, G. 1998

The product complexity and architectural coupling found in airborne radar provided the prime contractor strong sources of value chain control. Even if the various elements were sourced from third-parties, the quantity of architectural knowledge required to effectively integrate the pieces would prohibit them from servicing the system once fielded. Additionally, few companies could afford the expensive test equipment, testing ranges, and flight hours and provide all of the technical capabilities required to integrate and validate these systems. Architectural complexity and access to these resources provided radar houses such as Raytheon and Westinghouse significant sources of competitive advantage. Additionally, the capabilities provided by these systems are valued at a premium by the DoD as they are prime contributors to success of platforms that perform crucial warfighting functions. These radar houses were highly profitable as the value chain for airborne radars was enormous. However, while the DoD valued the functionality that mechanically scanned radars provided, this architecture left much to be desired in their performance, price, and reliability.

Electronically Scanned Arrays

Recent advances in electronics manufacturing have led to the evolution of airborne radar. The functions provided by the MSA's large, analog, high power transmitter, receiver, duplexer, and antenna have been repackaged into small, digital, low power Transmit / Receive (T/R) modules. These T/R modules integrate a low power solid state transmitter, a low noise amplifier receiver, and a phase shifter all into one easy to manufacture module and are the foundation of modern Electronically Scanned Arrays (ESAs). Hundreds of identical T/R modules are combined together on a backplane and work in unison to perform the radar's signal transmit and receive functions. Unlike Mechanically Scanned Arrays, ESAs do not require that the array be physically aimed at a target to detect it. ESAs utilize constructive and destructive interference between the T/R modules to create a near instantaneous (<10 nanoseconds) steerable beam (+-60 degrees).

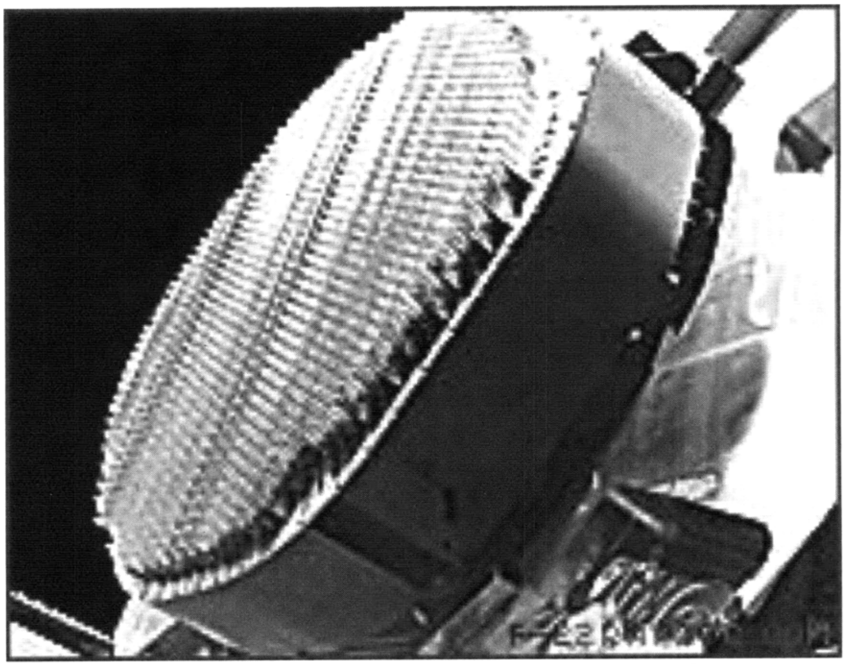


Figure 27: F/A-22 AN/APG-77 Multi-function AESA – Source: NorthropGrumman.com

The modern ESA systems offer many benefits over MSAs. The additional timeline provided by the rapid slewing of the ESAs beam greatly improves the quality and number of simultaneous target tracks the radar can provide. The elimination of the MSA's hydraulic slewing system and the associated vibration management technology, greatly improves the weight, cost, and reliability of the system. In fact, ESAs can have extremely high system availability rates. ESAs have much fewer single points of failure than MSAs and the interfaces between components are of much lower power. The low power and solid state design of T/R modules give them high life expectancy. Additionally, ESA architecture enables graceful degradation of the system as a considerable percentage of T/R modules may fail before system performance is significantly impacted. The expected lifecycle of modern ESA can be more than twice the lifetime of the airframe it is attached to.

The ESA architecture enables effective management of the system behaviors and functions that induced architectural complexity and coupling in MSA architectures. ESA systems are significantly lighter and smaller than MSAs. The lack of moving parts minimizes the effects of vibration. An ESA architect spends much less time managing these constrains and behaviors that were so troubling in MSA systems. Additionally, the low power digital signaling between ESA components greatly reduces the inter-module coupling of the modules. The T/R module array is essentially decoupled from the rest of the system in the design domain, further reducing design complexity. Decoupling the antenna from the remaining system has allowed the other components to modularize as well. Power supplies and processing capabilities have modularized and standardized as well.

This reduction in architectural complexity and inter-module coupling has had significant impacts on the radar design process. The ESA architecture is highly scalable as the same basic architecture can be reused for various levels of performance and operating conditions by simply adding or subtracting components. The system architect can design more powerful and higher accuracy radars by simply growing the number of T/R modules, power supplies, and processing capabilities. While significant effort is still required to integrate and tune the system, the design process of the various components is much more modular than it was in MSA systems. Modularization of design teams have facilitated economies of scale and learning in the design process. As a result, T/R module technology is rapidly improving and the improvements are spread to many design programs.

Modularization of Radar Processing

Radar processors have provided similar functionality throughout the evolution of the radar. Processors take the signal information and perform all of the complex mathematical operations required to filter out signal noise and identify targets. Radar's signals travel at the speed of light to and from their targets and can have several pulses simultaneously on their way. Performing all of the calculations within this tight timeline can require enormous processing capabilities. However, the size, weight, and power constraints of airborne radar can limit the processing power available.

Radars have traditionally delivered the required processing power by identifying opportunities to match the algorithms to the processing hardware. The performance improvements enabled through optimization of software and hardware created strong integrative forces within the processor. This tight integration necessitated the development of unique software to control each radar system. However, recent advances in processing speed are beginning to decouple the processor from the algorithms. Commercial processors are now fast enough that processing resources can be abstracted from the algorithms used to control the radar. Reuse of algorithms and radar control software is becoming much more common. A write-once-use-everywhere platform should be available in the near future.

Potential Effects of MOSA

The evolution of airborne radar architecture has had significant impacts on the value chain for these products. The modularization of the architecture has enabled many improvements in the performance of the system. The reduced architectural complexity and reusable product platforms have greatly improved the effectiveness of the design process. Modularization has increased inter-program collaboration through the use of standardized power supplies, processors, and arrays. Design programs for ESA radars are significantly shorter and inherently less risky than MSA systems.

While program effectiveness has improved, reduced product complexity and architectural coupling has significantly eroded Aerospace's value chain control for these programs. Third parties frequently win support contracts for airborne radar subsystems such as power supplies and processors. Historically, the prime contractor would eventually recapture these support contracts as the third parties would lack the architectural knowledge required to effectively support these products. However, additional modularization has increasingly enabled third parties to win and keep these support contracts.

MOSA threatens to accelerate this loss of value chain control. The DoD's procurement community has recognized that the modularization of the radar offers many opportunities to achieve higher economies of scale and learning outside of Aerospace. T/R module production represents nearly half of the recurring cost of an airborne ESA. This cost could be significantly reduced by leveraging additional production scale. Firms in industries such as telecommunications and wireless networking have the relevant manufacturing capabilities and access to enormous sources of production and procurement scale. ESA design programs are increasingly under pressure to outsource T/R module production. While intellectual property and proprietary interfaces currently tie T/R module production to the architecting firm, MOSA is enabling the DoD to outsource these services.

Customers, such as the Navy's SEWIP program, have leveraged MOSA to facilitate the decoupling of the value chain through the creation of modular and open system architectures that would allow outsourcing of the production of these T/R modules. SEWIP's MOSA strategy is to develop multiple sources of supply that would ensure competitive prices for the supply and support of SEWIP throughout its lifecycle. SEWIP is not only lowering acquisition costs for its program, but sowing the seeds of improved acquisition capabilities for other programs. SEWIP is paying firms to develop the organizational capabilities required to design and produce T/R modules, essentially growing competitors for Aerospace.

Unlike the system level performance of a radar, the customer valued performance metrics of T/R modules are easier for customer to specify and evaluate. This objective evaluation of T/R module performance combined with additional suppliers would greatly increase competitive pressure. Aerospace firms currently lack the scale or manufacturing efficiency found in consumer electronics industries. Without additional sources of competitive advantage, Aerospace may one day lose T/R module design and production completely. This would be highly disruptive as T/R modules now encompass many of the technology capabilities that are currently the basis of competitive advantage between radar suppliers. These capabilities would likely fade over time without in-house design and production of T/R modules.

The complexity and resources required to integrate ESA radars continue to provide the integrator significant value chain control for the remaining design, production, and support services. However, increased architectural stability and MOSA are enabling and incentivizing further decoupling of the ESA architecture. Power supplies, processors, and software, which once conveyed distinctive performance advantages, are increasingly becoming commodities. The activity network and potential opportunities to create scale in airborne radar will continue to grow. It may only be a matter of time before the technologies required to modularize production and integration of ESAs are invented. The radar architectures that support modularity of design, production, and use would greatly increase the competitiveness of the industry.

Airborne radars were once an ideal product from a business perspective. They were large integrated systems that once designed, guaranteed decades of profitable business. The modularization of airborne radar, while highly beneficial to its users, may prove to be extremely disruptive to Aerospace's continued ability to profit from these systems. The MOSA procurement environment will serve to accelerate this disruption.

5. Avoiding Architectural Disruption

5.1. *Characterizing the Threat*

MOSA's impact on Aerospace is likely to vary by company and product. As indicated in the previous section, the DoD's ability to modularize procurement will be determined by the inherent integrality of each product which extends beyond the purely technical design domain. Legal, economic, or political forces may prevent the DoD from realizing the desired modularity-enabled design, production, and usage capabilities. Additionally, the DoD has several organizational capabilities that it must develop before achieving the goals of its MOSA strategy. However, this uncertainty of how and when MOSA will impact Aerospace is the foundation of disruptive threat. Firms must begin the process of preparing their organizations to meet the challenge of disruptive change.

It is certainly possible that MOSA will have no effect on many Aerospace programs. Some products are too inherently integral to enable modularity of design, production, or use capabilities. Many of these weapon systems are one of a kind and few firms with the required specialized capabilities exist outside of the prime contractor leaving few opportunities to access external technology or scale. The costs of developing a standardized modular architecture or the required inter-program communication and coordination capabilities may outweigh any opportunities to leverage scale. Additionally, many of these systems are undergoing high rates of architectural innovation. The performance benefits offered by architectural innovations might outweigh the cost improvements of standardization. The optimal architecture for each warfighting capability will be determined by the customer's preference for system performance and affordability. While modular architectures might be appropriate for many applications, integral products will be optimal for some systems.

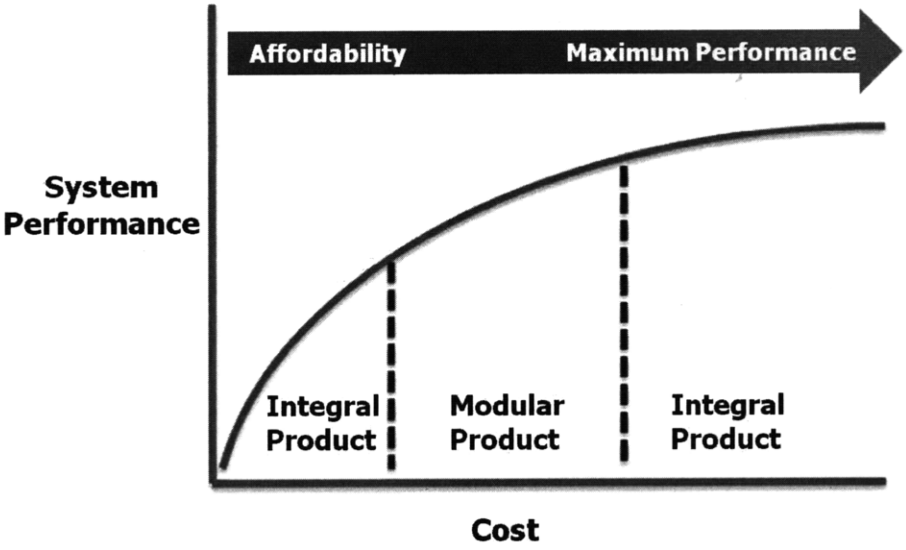


Figure 28: Optimal System Architectures Determined by Customer Values

While MOSA may have little impact for some products, many systems present attractive opportunities to create scale and leverage world-class capabilities found outside of the prime contractor. The disruptive effects of MOSA for these systems can be characterized by its ability to slow the rate of architectural innovation, the rate in which new component functions and linkages are introduced. Products undergoing the fastest rates of architectural innovation are driven by the high performance demands of their customers to identify opportunities to improve product fitness by optimizing the choice and arrangement of components. These products hinder standardization and limit opportunities to leverage scale as their components and interfaces are constantly changing. Therefore, many products with high rates of architectural innovation are less likely to be disrupted by MOSA.

For systems with currently low rates of architectural innovation, MOSA is unlikely to impact the architecture of these products as they already offer opportunities to create scale. Additionally, the ways in which DoD values and uses these systems will likely remain unchanged. However, MOSA will likely reduce the prime contractor's value chain control and allow the DoD access to competitors products and services. The products that will fall into this category of disruption will be easy to identify and create effective strategies for.

MOSA is most disruptive for integral products with high rates of architectural innovation whose changing customer performance / cost preferences now favor modular product architectures. In a MOSA procurement environment, the benefits of additional modularity and standardization now outweigh the performance benefits offered by the current architecture. For these products, MOSA may bring about new modular and standardized product architectures. These new product architectures will fundamentally change the ways in which the DoD values, purchases, and uses the system have the greatest disruptive potential. Aerospace is a highly mature and specialized industry. They have evolved complex enterprise architectures and sophisticated organizational capabilities that match the current competitive context. This combination organizational complexity and industry maturity will make it very difficult to assess the impacts these new product architectures have on the competitive context and create effective strategies. Standardized modular and open product architectures enable the following customer capabilities with possibly disruptive effects on the competitive context:

- Ability of customer to match its needs to a system architecture
- Intra-program Coordination and collaboration of product development, production, and support
- Ability to drive make / buy decisions – identify and evaluate customer valued capabilities outside of the prime contractor
- Decoupling the production / support / upgrade services from the system architect

These new capabilities will likely change the ways in which the customer will value, procure, and use your products and organizational capabilities. If modularity enables the customer to match its needs to system architectures without the architect, it could significantly deteriorate the customer's value for architecting capabilities. The acquisition community currently lacks the ability to coordinate between programs or incentivize programs to work together. If the DoD evolves the capability to value and incentivize coordination, contractors that can mitigate the cost and complexity of inter-program coordination and collaboration will gain competitive advantage. As systems become modular and contractors are unable to leverage positions to gain value chain control, the contractors that deliver superior customer-valued capabilities will capture the greatest value in the MOSA-era. Firms must be able to honestly assess how they currently create and capture value and work towards developing new effective competitive strategies.

5.2. Products Likely Affected

Aerospace should anticipate changing competitive context by evaluating the DoD's desire and ability to slow architectural innovation for each of their products. Guidelines for evaluating their product portfolios should include the:

- Inherent modularization of the architecture
- Opportunities to create scale
- Ability of customers to drive architectural change
- Ability of suppliers to resist architectural change

Products have varying degrees of inherent modularity. Some products lack what Schilling calls "synergistic specificity," meaning its components function relatively independently and can be recombined in a variety of configurations with little loss of system performance. A home stereo receiver is a good example of low synergistic specificity as its designers have a large number of receiver components and architectures that would result in a product with the desired performance.

Products with loose environmental operating constraints or low performance expectations typically feature low synergistic specificity. For example, the performance required by an Indy race car necessitates tight coupling between all components of the car to achieve the desired performance. The selection of components such as side view mirrors may receive little attention in commercial automobile manufacturing. Yet in Indy racing these components would require significant engineering skills and expertise to assess the aerodynamic properties and weight impacts on system performance. Products that feature low synergistic specificity or offer adequate levels of performance are more likely to be impacted by MOSA.

Many products provide the DoD opportunities to create scale. Products that are members of product families or have large production counts are obvious MOSA targets. Modules that provide core functionality present in several different applications, such as power supplies, are also likely to be standardized. Many programs contain sources of scale that are not immediately obvious. For example, systems that require frequent servicing of components or utilize consumables provide incentives to modularize. Additionally, systems that are comprised of components with varying rates of incremental innovation benefit from modularization. Modularity reduces the cost of incrementally improving the system over time as new technologies become available. Firms should evaluate the opportunity to benefit from economies of scale and learning throughout all lifecycle activities of the product. However, the potential return from these opportunities to create economies of scale and learning must exceed the investment required to achieve them. Therefore, systems with high system lifecycle costs will be the primary targets for MOSA.

MOSAs impact on architectural innovation and Aerospace's value chain control heavily relies on its customer's ability to drive architectural evolution. The architectural complexity of some products is beyond the DoD's engineering capability. For example, it is very difficult to assess system level performance impacts of design changes with airborne radars. Flight testing completed radar is about the only way to verify that a change produces the desired effect. This architectural complexity provides the architect / integrator firms strong control over the radar architecture and prevents the DoD from changing the product or driving make/buy decisions.

However, the DoD may not need the technical capability to drive architectural change. Aerospace is limited in who they can sell their products by U.S. export law. This legal barrier to competition provides DoD oligopsony from which it derives strong market power over its Aerospace suppliers. This competitive environment creates strong incentives to deliver their products on the DoD's terms. This MOSA procurement environment is incentivizing firms with weak sources of competitive advantage to identify innovative ways to provide the modularity-enabled capabilities desired by the DoD. These firms are offering products that enable unique modularity-enabled capabilities as sources of competitive advantage. Product architectures will likely become increasingly modular and open over time as Aerospace firms compete to win procurement contracts. Only suppliers that own difficult-to-replicate technology capabilities or unique resources will be able to maintain their closed product architectures against obvious benefits of scale.

5.3. *Eroding Foundations of Competitive Advantage*

Current foundations of competitive advantage for the DoD's technology acquisition programs are based on unique organizational capabilities to manage product complexity. In fact, firm's ability to profit from cost-plus technology development programs is directly derived from the product's inherent complexity and its organizational capabilities to manage this complexity.

Negotiated profit of cost-plus contracts are largely dictated by the FAR's Weighted guideline system which provides the government's acquisition team guidance and limits for negotiating profit. The DoD's evaluation of the product's inherent complexity and the uniqueness of the firm's ability to manage this complexity largely determines what profit percentage will be allowed, typically 0 – 12% profit.

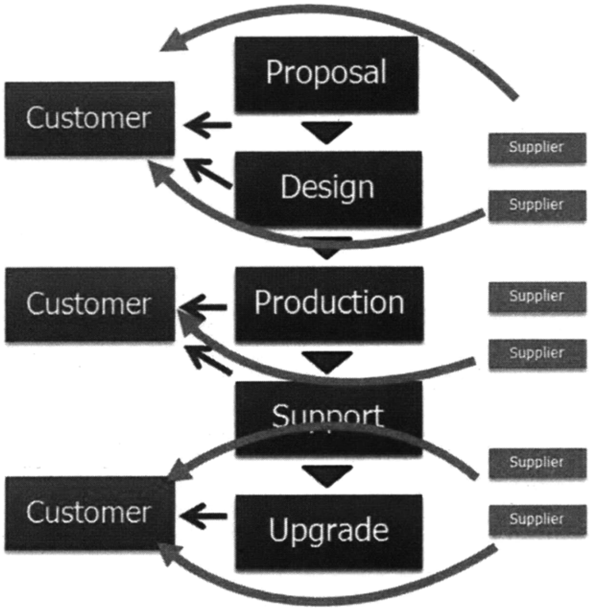
Contract Price = Negotiated Profit + Allowed Indirect cost + Management Reserve + Direct Cost

Management reserve is the programs risk budget, a pool of money set aside for the contractor to use to mitigate technical, cost, or schedule problems as they materialize. Programs with large inherent risks are allocated larger management reserves. As the contractor is able keep the remainder of this budget once it meets the terms of the contract, management reserve provides incentives for desired contractor behavior even in the absence of inter-supplier competition. Management reserve is a significant source of Aerospace profit and can exceed the size of the negotiated profit if the program is managed wisely.

If standardized modular architectures arise, the perceived architectural complexity of the product and the uniqueness of a firm's technology competencies will fall. This will eventually lead to lower negotiated profits. Additionally, modularity should improve the program's ability to manage risks which could result in reduced management reserves for these contracts. A slowing of architectural innovation and modularization is in itself disruptive for these cost plus products.

As the product architectures evolve, firms must create the organizational capabilities that leverage architectural stability and take advantage of opportunities to leverage scale as they are identified. If product architectures become standardized and the relevant technical capabilities become widely available, the focus of competition may shift entirely from product innovations to process innovation. If modularity sufficiently reduces the inherent complexity of these products, the DoD may transition from cost-plus to firm-fixed-priced products. Such a shift would provide firms with superior design process capabilities significant competitive advantage.

Firm roles and scope may shift with the foundations of competitive advantage. The architect / integration role is currently desired positions in Aerospace as architectural knowledge typically provides significant competitive advantage throughout the program value chain. However, the value may shift to the component suppliers if the architecture modularizes. Modular products could even allow the DoD to take over integration and repair services itself. Aerospace must continually reevaluate their assumptions about the ability to capture value from these roles and the customer's value for their organizational capabilities.



Capabilities:

- ~~Management of product complexity~~
- ~~Mitigation of customer induced complexity~~
- ~~Integrative capabilities~~
- ~~Cradle to grave support~~
- ~~Core competency in relevant technologies~~

Positions:

- ~~System level information~~
- ~~Architectural information~~
- ~~IP ownership~~
- Experience
- Existing customer relationships / brand

Figure 29: Slowing Architectural Innovation Erodes Aerospace's Foundations of Competitive Advantage

5.4. Signals of Change

The DoD is lacking many of the organizational capabilities required to implement its MOSA strategy. MOSA will take some time until its full impact is felt in Aerospace. As firms work towards moving their organizations towards a state of MOSA preparedness, they should keep an eye on the indicators of competitive context change:

- Emergence of new dominant designs
- Narrowing of customer valued product performance parameters
- Greater customer participation in make / buy decisions
- Expansion of the activity network
- Changes in firm scope
- Lower contract prices or profitability
- Transition from cost-plus to firm-fixed price contracts

In order to avoid disruption, firms should continually reevaluate their product architectures, the ways in which the customer value, purchase and use these products, and the changing competitive context in Aerospace.

5.5. Organizational Anchors

MOSA is an embodiment of changing customer values, new customer procurement and usage capabilities, and new product architectures and represents an enormous change in the competitive context. MOSA will prove to be highly disruptive unless Aerospace firms anticipate the change and develop strategies and capabilities required to effectively compete. However, several organizational anchors hinder their ability to identify changes in the competitive context and develop effective strategies.

Polaroid demonstrated the organizational inertia that can develop over a long successful history in a mature stable industry. Like pre-digital photography, Aerospace is also a mature stable industry. Many of the products, industry competitors, and customers have been relatively constant for decades. Aerospace's organizational architectures and cultural beliefs are strongly adapted to this stable competitive context. As such, these firms lack strong organizational capabilities for meeting the challenge of disruptive change.

MOSA is one of many DoD strategies to improve acquisition performance from the last two decades. The relative small impact of procurement strategies such as COTS and Performance Based Logistics have had on Aerospace has conditioned these firms to utilize "active waiting" strategies rather than proactively responding to potentially disruptive threats. Additionally, MOSA is a very subtle change as designing MOSA compliant products does not require new organizational capabilities. In fact, at the program level, MOSA is simply a new set of customer design requirements that must be flowed into the design process. The conditioned behaviors of management combined with the subtlety of MOSA will hinder Aerospace's ability to avoid disruption.

IBM demonstrated the need and complexity of developing successful new product strategies aligned with the needs of the enterprise. The organizational architecture of the PC design team allowed it to develop a product strategy that lacked enterprise alignment. Additionally, its product strategy was based on incorrect assumptions about IBM's sources of competitive advantage. While the PC was highly successful, its product strategy eventually had disastrous effects on IBMs value chain.

Aerospace is facing similar challenges in enterprise communication and coordination of strategy. Aerospace firms are enormous complex entities. Their product and technology scope enables them to weather changing customer preferences for warfighting capabilities. Their organizational architecture is aligned with mitigating the organizational cost of variability in customer needs. However, the resulting organizational inertia and complexity will make it difficult to effectively respond to MOSA.

Aerospace's activity network includes an enormous number of customers and suppliers. The realizations of their products require the development of a vast number of technology and operational capabilities. The size and complexity of these organizations creates pervasive causal ambiguity. Few people have visibility into how their firm competes with its competitors or how a product is transitioned from conceptual design to the battle field. The causal ambiguity will prevent them from perceiving change in the competitive context and developing an effective strategy.

Aerospace's function/customer matrix organizational designs reduce the cost of coordination and managerial complexity involved in staffing new programs and reallocating personnel as these programs are completed. These matrix organizations lean heavily towards satisfying individual customers and away from functional organizations that create economies of scale or learning as few enterprise incentives or opportunities to improve program performance through scale exist. As MOSA is implemented, this customer leaning matrix organizational design will aid in identifying changing customer values for the firm's products as it emphasizes customer relationships and understanding chaining customer values. However, the customer leaning matrix will hinder its ability to leverage any opportunities to create scale. Additionally, this matrix design lacks strong product alignment. Each customer may procure a variety of products and technologies, product category experts are spread throughout the organization. The only organizations that specialize in a single product or technology are typically found in R&D groups that have few connections with individual programs.

This organization design results in several organizational behaviors that are particularly dangerous in a MOSA procurement environment. Programs are creating product architectures with little coordination with those who develop enterprise technology strategies. Additionally, the individual programs that are responsible for creating product strategy lack the resources or incentives to create a coordinated enterprise strategy. As programs are primarily incentivized to meet their customer needs, their products will likely deliver modular and open designs with little consideration to future value chain impacts. IBM demonstrated the potential problems that may arise from product strategies that lack enterprise alignment when the new product has the potential to cannibalize the remaining products.

Aerospace's enterprise architectures have several barriers that slow the rate at which information is disseminated and new organizational behaviors can arise. As these companies are comprised of firms from many acquisitions, they are large geographic and cultural divides between sites. Additionally, security restrictions require that many employees work in secure closed locations. As the DoD's values and the ways in which it procures and uses Aerospace's products change, these barriers to communication will slow Aerospace's ability to socialize the change in the competitive context and develop new organizational behaviors.

5.6. *Effective Strategy Formation*

Once the organizational anchors preventing assessment of the current foundations of competitive advantage are cleared, Aerospace must turn to quickly identifying strategies that are effective in this new competitive context. Strategy formulation can be divided into two product categories, products with and without existing dominant designs. Firm roles, opportunities for specialization, and foundations of competitive advantage are likely known in product categories with dominant designs. Markets where the current products undergo high rates of architectural innovation and lack dominant designs are more difficult to anticipate changes to the competitive context. We shall examine effective strategy formation in both of these product categories.

Product Categories with Existing Dominant Modular Designs

Products that are currently modularized or have slow rates of architectural innovation likely present obvious opportunities to leverage scale that lie outside of the current firm scope that are attractive to the DoD. As MOSA erodes the current foundations of competitive advantage, it is important to quickly develop new distinctive capabilities and positions. Effective strategies for this product category are:

- Leveraging product modularity to create superior organizational capabilities
- Utilizing current positions to create capabilities that differentiate you from firms wishing to enter your value chain
- Gaining control of valuable world-class capabilities found outside of your organization

As MOSA begins to erode the sources of competitive advantage, Aerospace must identify opportunities to leverage product modularity and create organizational capabilities that are superior to competitors. We have identified many ways in which modularity can improve design and production process effectiveness. One of the best ways an organization can align itself with modular and stable product architecture is through the utilization of product-oriented organizational designs that can facilitate rapid incremental improvement of modules. When appropriate, product-oriented organizational designs leverage the stability of product interfaces and functions to create economies of scale and learning. These organizations facilitate the communication and coordination that is so difficult achieve in Aerospace. This alignment of enterprise and product architectures is essential in supporting many of the foundations of competitive advantage in modular product industries.

These specialized product-organizations must create world-class capabilities in realizing incremental innovations that improve their modules on non-commoditized performance parameters. When this capability to innovate is based upon economies of scale and learning, it is important to protect and expand current sources of scale. Finding new customers and markets for these standardized components is an ideal way to create additional economies of scale. MOSA itself presents one of the best ways to create economies of learning. The DoD intends to put as much architectural information as possible in its IP repositories, such as the Navy's SHARE system. Powerful organizational capabilities can be created through the accumulation and dissemination of the architectural knowledge on these repositories.

As these new product-oriented organizations are developed, it is imperative that the firm maintain the ability to identify and create architectural innovations. Innovation at the system level is one of the best strategies for differentiating yourself in a field of commoditized products. Product design organizations are incentivized to improve products around narrow ranges of product performance parameters. Henderson and Clark (1990) identified how their specialized processes, information filters, and incentive structures tend to limit their ability to identify and realize architectural innovations.

While process optimization offered by product organizational designs are necessary, they are insufficient to create sustainable competitive advantages where the required capabilities are widely held and sizeable opportunities to capture value exist. Aerospace must create distinctive and difficult to replicate capabilities to drive improvement of modules along non-commoditized performance parameters. Aerospace's current experience, scope, and scale positions that may enable these firms to create capabilities that differentiate them from firms wishing to enter their value chains. For example, current customer relationships provide Aerospace insight to how their customers value and use their products. This provides them an advantage in identifying product parameters that are under-performing by the current generation of products.

Currently fielded products provide many opportunities to create unique organizational capabilities that would be difficult to replicate by companies new to Aerospace. Aerospace firms can leverage learning from the repair centers to deliver high-reliability products. Knowledge of the customer's operating environment and confidence in estimating system reliability enables Aerospace firms to provide product warranties and negotiate Performance Based Logistics contracts that are highly desired by the DoD. Additionally, Aerospace has many opportunities to create cost advantages through product reuse. Logistics handbooks and FAR documentation are very expensive for the DoD to create. Training logistics personnel to effectively service systems is also expensive. Reuse of fielded products can greatly reduce the DoD's total cost of ownership.

It is unlikely a single Aerospace firm will be able to create all of the world-leading organizational capabilities required to capture the entire value chain. When external world class capabilities exist, firms should try to monopolize access to these capabilities if they are valuable and difficult to replicate. Companies often utilize sourcing partnerships to obtain access to needed organizational capabilities. For example, Ford outsources many of their engines and transmissions to firms that have access to enormous sources of scale that Ford would be unable to achieve on its own. Their suppliers enable Ford to reduce product costs and capture additional value from their products. In return the suppliers are rewarded with stable sources of scale and non-commoditized profits. Securing access to these distinctive capabilities through synergistic partnerships will provide firms positions of competitive advantage.

However, note that outsourcing components will eventually lead to diminished technical capabilities over time. In contrast to Ford's outsourcing strategy, Honda utilizes its mastery of engines and transmissions provide it competitive advantage through the design of products with superior fuel efficiency and reliability. Outsourcing should be done strategically as many technical capabilities are foundations of key sources of competitive advantage. Aerospace firms are technology job shops, they are what they build. Cohen and Levinthal defined how a firm's capacity to identify valuable innovations and create new products, its absorptive capacity, is heavily path dependent. Outsourcing technology capabilities will eventually limit a firm's absorptive capacity and its ability to drive customer valued innovations and its strategic options as the competitive landscape evolves. Identifying and protecting these key technical capabilities are an important piece of the strategy formulation process.

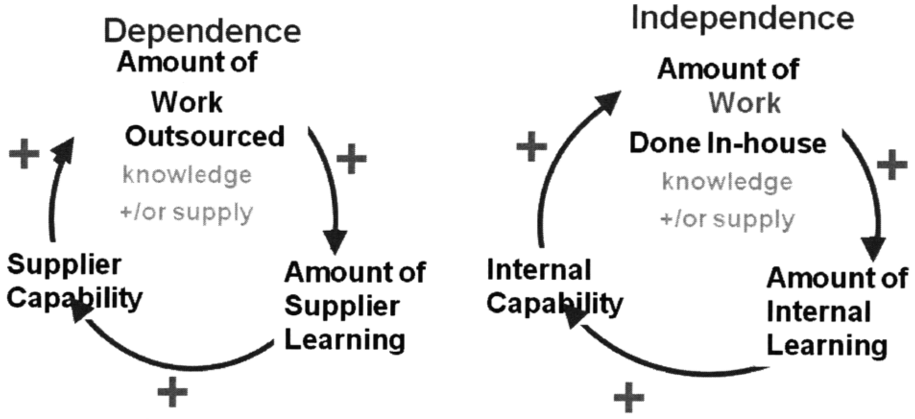


Figure 30: Constructive Leaning Loop of Capabilities – Source: Fine 2004

Product Categories without Existing Dominant Modular Designs

Modular products enable firms to develop superior capabilities by creating economies of scale and learning. As opportunities to specialize and create scale emerge, firm scope will likely change. Modularity and openness greatly reduces barriers to market entry and may lead to growth in the activity network. Increasing number of competitors and opportunities to create economies and scale and learning will raise the rate and diversity of innovation. This change in product architecture will have unpredictable impacts on the competitive landscape. It will be difficult to predict who will create and capture value in this new competitive context.

Products that are modular in design, production, and usage incentivize specialization which typically results in several unique industry roles; system architect, platform leader, module player, and system integrator. Which roles capture value is determined by each product's particular competitive landscape. We shall examine effective strategies that have been developed for each role. However, note that many of these strategies have strong first-mover or scale advantages to them. It is imperative that as the competitive context shifts, firms quickly move to where the value is being captured and implement the appropriate strategies.

Product Architect

It is the architect who creates the modularization design rules and defines the visible information used by module designers. Architecting a modular product requires and develops broad technical and operational capabilities that would enable it to move into any of the other firm roles. The architect has a unique opportunity to initially determine the product architecture and a temporary monopolization of architectural knowledge. Architecting the product is a valuable position as the product architecture largely determines the firm's ability to capture value. By aligning the product's architecture with the organization's current capabilities and positions ensures that your foundations of competitive advantage are relevant with the new product. The architect determines which modules have the largest contribution to system level performance. Strategic functional allocation provides the architect competitive advantages in customer valued modules. Introducing design dependencies that couple the modules where you have competitive advantage to valuable modules that you lack competitive advantage may enable the firm to extend its ability to capture value.

Sun Microsystems provided great examples of architectural strategies to capture value on a modular product in competitive environments. They identified opportunities to tightly integrate the processor and memory in a way that provided customer-valued performance improvements and strong sources of platform control. This architecture was aligned with Sun's organizational capability to rapidly innovate in processing design and develop operating systems that leveraged these improvements. Additionally, Sun's product was strategically architected to facilitate low cost manufacturing which provided it a cost advantage even though it utilized similar components as its competitors. Sun's product architecture was able to strike a balance between leveraging complements from other products while maintaining strong value chain control. Its architectural strategy was highly effective.

The choice in product architecture should be make carefully as once the modular architecture is defined, the network effects of standardization creates strong incentives to limit architectural change. This limited ability to introduce architectural change can devalue the architect's capabilities. IBM demonstrated this rapid devaluation of architectural knowledge once the architecture is defined. Customers that were satisfied with the performance presented by the real options of the current architecture valued only incremental module innovations. The architect must identify new markets for its architectural knowledge. Customers that prefer performance or cost levels that are unachievable by the current product are ideal markets for architectural innovations. While IBM was displaced from the consumer PC market, it continues to leverage its PC architectural knowledge to create super computers for large institutional customers. IBM's mastery of the PC enables it to utilize its components in innovative ways that deliver unmatched performance.

Unlike IBM, Apple was able to earn substantial profits from the commoditized PC platform. It innovated in product usability and style, which were underperforming product parameters for many customers. The architect may also avoid devaluation of its architectural knowledge by raising the rate of architectural innovation. By constantly identifying customer-valued innovation that required change the components and interfaces, the architect can reduce the attractiveness of standardization.

Strategic value destruction is also an option of the architect. If the architect's firm lacks competitive advantage in offering a customer-valued module, then it may choose to eliminate competitor's ability to create distinctive positions. Open architectures and public availability of architectural knowledge would make creating unique positions difficult and enables the customer to capture additional value from these modules.

Platform leadership

The mission of the platform leader is to drive the evolution of the product architecture and its business ecosystem to grow the size of the value chain and its piece of the pie. Platform leaders influence the product and ecosystem by:

- Creating or adopting architectural innovations
- Aiding the success of your allies
- Preventing competitors from capturing value

For example, Intel heavily invests in creating and ensuring the adoption of architectural innovations that improve the value of the PC platform. Intel invented the USB interface which greatly aids the development and use of complements such as digital cameras and mp3 players. Intel itself captures little value directly from the creation of USB. However, USB grows the total PC value chain, indirectly benefiting Intel.

Platform leadership requires the help of complementors to become successful. In order to ensure your choice of architectural innovations are adopted by the ecosystem, you must convince and incentivize others to follow your lead. Ownership of platform interfaces and standards are typical methods of obtaining platform leadership. However, MOSA presents few opportunities to own architectural knowledge.

WHY – oly – modularity and openness - prevents you

Establishing a reputation as the ecosystem's "Thought Leader" can be an influential position with customers and complementors and an effective strategy in a MOSA procurement environment. IBM builds a reputation as a leader in supercomputing through public demonstrations of its computing prowess, such as pitting its products in competitions with world champion chess players.

Other methods of establishing a thought leadership position is to establish and lead relevant standards setting bodies and excel at creating architectural innovations. Intel has repeatedly demonstrated its ability to work with complementors and drive the adoption of their architectural improvements. Its success has become a self-fulfilling prophecy. Standards introduced by Intel are assumed to eventually be included in the architecture by complementors. Incentivizing complementors to adopt your architectural innovations is also an effective strategy. Creating an installed customer base for your architectural innovation incentivizes the development of complements that will make the new platform more attractive for additional customers. Also, ensuring ecosystem stability for complementors improves the expected return of investing in new architectures. Superior execution or ownership of a core platform element can also provide platform control. For example, Microsoft wields enormous power of the PC industry and captures value from many of the customers and industry members through its ownership of the PC's operating system.

Module player

The module players conform to the architecture, interfaces, and test protocols established by the architect to deliver modules that excel at customer-valued performance metrics. Modularity provides many firms access to the architectural information required to compete as a module player. Additionally, competition between module players is focused around a small number of key performance parameters. Firms in these roles struggle to create distinctive capabilities and positions. However, these can be difficult to create as modularity enables firms to rapidly copy the innovations of others.

The openness of MOSA compliant systems will make it especially difficult to create competitive advantages based on ownership of interfaces and standards. However, innovating in non-commoditized directions that are subjective or difficult for the customer to evaluate can provide distinctive competitive advantage. Unlike architectural innovations, these incremental innovations can be protected with intellectual property in a MOSA environment. MOSA allows the ownership of module IP in order to incentivize investment in the platform, as long as this ownership does not interfere with its DoD's modularity of use capabilities. It is important to protect valuable innovation in module improvements. Aerospace firms must identify and fully fund development activities that may result in valuable module IP as the DoD is entitled to rights on any IP developed under contract. This is particularity important in a MOSA environment as architectural knowledge repositories will transfer these innovations to your competitors.

Integrator

The integrator identifies customer needs that are achievable within the real options presented by the modular product architecture. These firms then leverage product modularity and a wide selection of components to rapidly and affordably meet these diverse customer needs. Modularity greatly reduces the cost and complexity of the integrator's required capabilities. Therefore integrators have few distinctive sources of competitive advantage and typically compete through optimization based strategies. It is important that integrators develop superior procurement, integration efficiency, and customer service capabilities. As these capabilities are strongly benefited by economies of scale, integrators are under constant pressure to identify new sources of scale.

As integrators have direct customer interaction, they are in a unique position to understand how their customers value, purchase, and use the product. Integrators should develop strategies that leverage this position. For example, Dell created competitive advantage in the home-PC market by providing excellent customer service even when faced with strong price competition. Integrators should look for opportunities to create such distinctive positions. Strategic partnerships with complementors or customers would provide it these positions. As there are strong economies of scale benefits to integration of modular products, it is likely that a single integrator per product platform would exist in Aerospace.

5.7. Key Takeaways

There are few key ideas that the reader should take away from this paper:

1. MOSA is NOT just new technical requirements, it is an embodiment of changing customer values and new procurement capabilities
2. Aerospace should anticipate a change in ways in which their customers value, purchase, and use their products
3. Contractors that deliver the specialized capabilities desired by its customers will capture greater value from programs
4. Organizational beliefs will determine Aerospace's ability to effectively respond to MOSA

As the DoD implements its MOSA strategy and new product platforms emerge, Aerospace must re-evaluate their products, processes, organizational designs, and behaviors. It is imperative that they quickly begin to create new sources of competitive advantage that will help them maintain value chain control. As opportunities to create scale arise, they should leverage architectural standardization and modularity to create superior program execution capabilities. Their reputation as through leaders and current scope and scale can provide them significant sources of competitive advantage in this new era. Yet these positions will erode without action from their management.

Don't do a Polaroid

Re-evaluate your beliefs about the world!

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