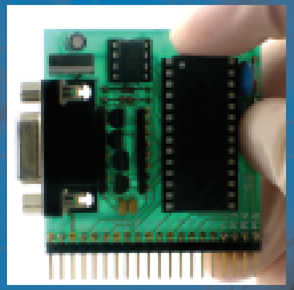


"American manufacturers are a cornerstone of the American economy and embody the best in American values. They enhance U.S. competitiveness while improving lives domestically and internationally."

Manufacturing in America: a Comprehensive Strategy to Address the Challenges to U.S. Manufacturers

January 16, 2004

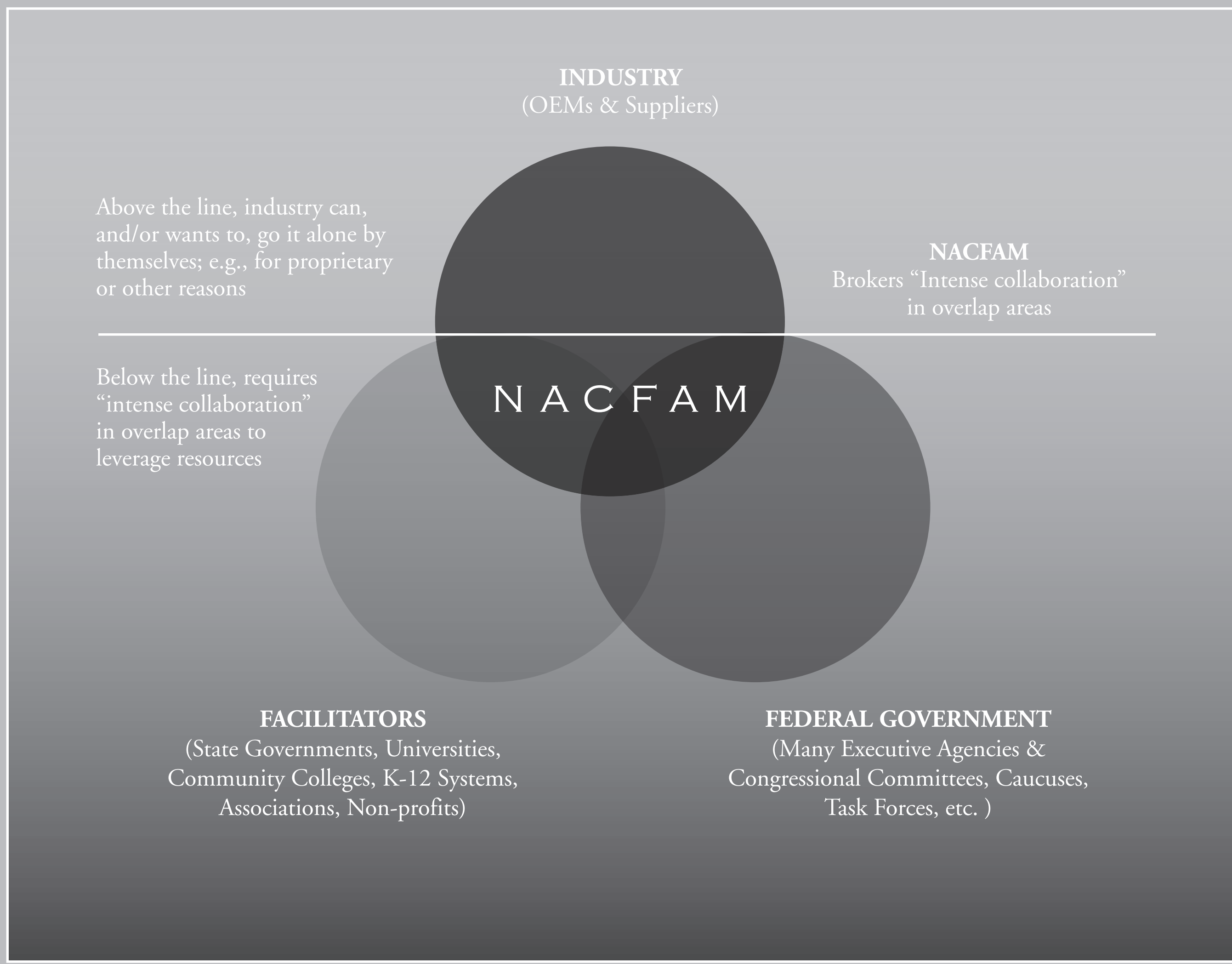




THE NETWORK-CENTRIC INNOVATION IMPERATIVE:

How Manufacturers Work with Their Suppliers to Develop New Products

NACFAM
NATIONAL COUNCIL FOR ADVANCED MANUFACTURING

ADVANCED MANUFACTURING "INTENSE COLLABORATION"



The National Council for Advanced Manufacturing (NACFAM) is an industry-led, 501(c)(3) research and education organization committed to enhancing the productivity and competitiveness of U.S.-based manufacturing. It develops national policies and programs to accelerate the development and deployment of advanced technologies and related workforce skills, as well as supply chain integration and performance improvement. This is done by providing manufacturers and government — reinforced by academia, research, manufacturing extension centers, and labor — a non-partisan, non-adversarial forum to work together to strengthen U.S.-based manufacturing.

More information about NACFAM can be found at **www.nacfam.org**

THE NETWORK-CENTRIC INNOVATION IMPERATIVE:

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Chris Hayter, Research Director

Fall 2006

NACFAM
NATIONAL COUNCIL FOR ADVANCED MANUFACTURING

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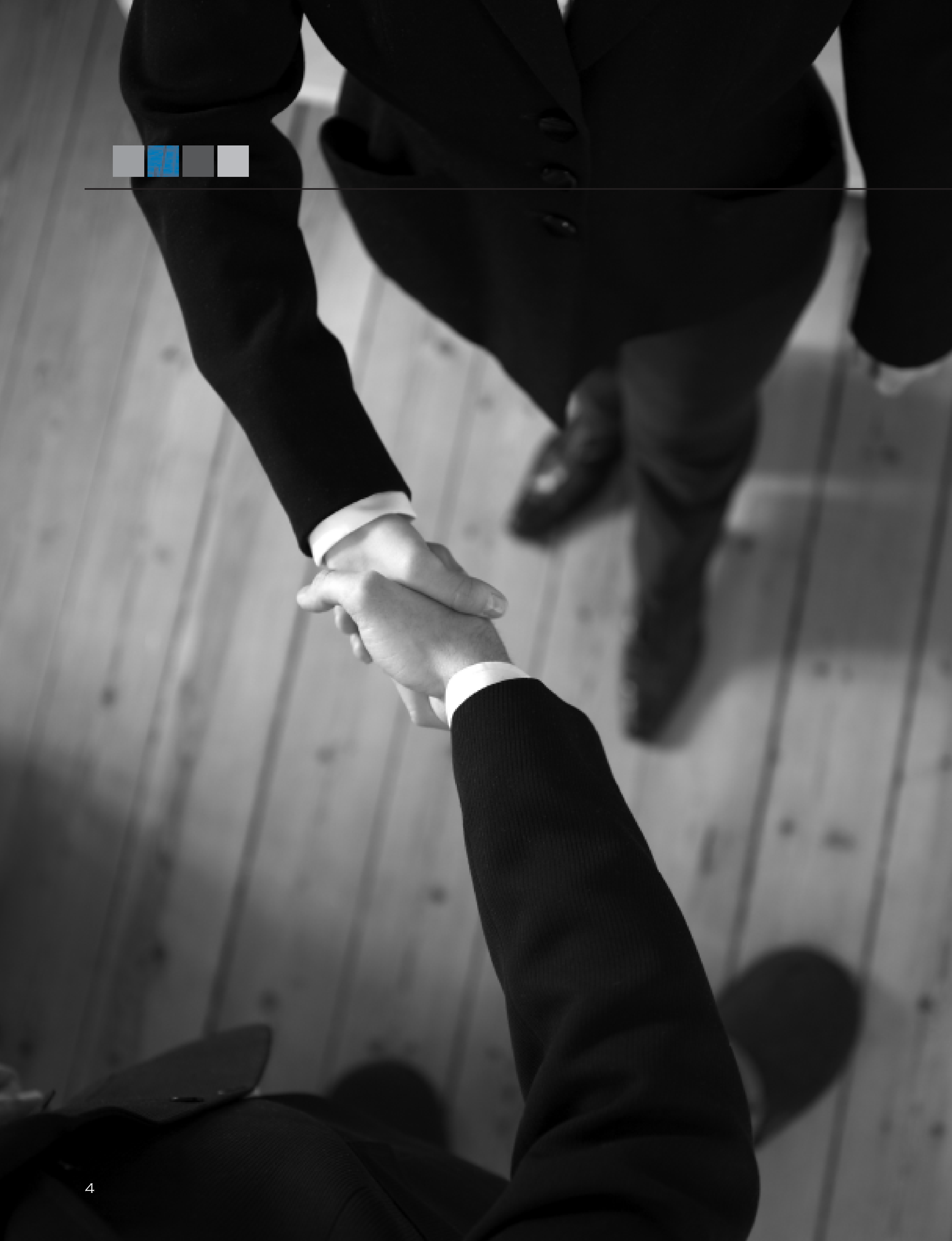


FORWARD

The Advanced Technology Program (ATP), part of the National Institute for Standards and Technology (NIST), asked the National Council for Advanced Manufacturing (NACFAM) to investigate the changing nature of innovation in American manufacturing.

At the time of the request, NACFAM was launching its Supply Chain Initiative to examine and identify impediments to achieving a competitive network-centric manufacturing environment and spur public and private stakeholders to work together to achieve multi-tiered network-centric manufacturing capability.

This supply chain effort has become one of the primary tenets of NACFAM's mission and, importantly, ATP provided a valuable opportunity to expand and deepen our scope of inquiry.

Our work has generated considerable enthusiasm among our members and others, within both manufacturing and policy communities, for the importance of public-private initiatives aimed at improving the overall competitiveness of U.S. manufacturing. However, if there is anything we have learned in our discussions with manufacturers and lawmakers alike, it is that, in general, "competitiveness" has no natural constituency and, as we mention in the last chapter, these discussions all too often become zero-sum arguments about whether or not government should be involved, rather than simply acknowledging that government plays a substantial role in our economy. In the face of an increasingly competitive global environment, we must shift the focus to *how* government should be involved and the *effectiveness* of that involvement. It is our hope that this report contributes to this dialogue.

We would like to sincerely thank all the participants without whom we would not have been able to complete this study. We are especially grateful to our industry liasons who not only put us in touch with numerous individuals within their organization, they provided important insights on which this report is based. These individuals include Paul Ericksen and Larry Burken from Deere and Company; Valerie Feliberti, Frederick Hale, and David Huntsman from Boeing Commercial Aircraft; Chuck Moritz from Lockheed Martin Aeronautics; Ed Morris from Lockheed Martin Missiles and Fire Control, Frank Ewasyshyn, Peter Weiss, and Bruce Beier from Daimler Chrysler; Gary Conley, Ken Bloemer and Susan Moehring from Techsolve, Steve Vangsnes and Mike Ketter from Harley-Davidson, and several other corporate officials who asked not to be mentioned by name.

We also extend our special thanks to Professors Charlie Fine, David Simchi-Levi, and Stephen Eppinger of MIT as well as Bill Killingsworth of the MIT Forum for Supply Chain Innovation who served as gracious partners and teachers in the conduct and composition of this study.

Most of all we would like to thank our sponsors, the Advanced Technology Program, whose generous support not only enabled the study of product development and supply chain management, it also contributed to our collective professional development and helped improve our relationship with NACFAM members. In particular, we would like to thank Marc Stanley, ATP Director, Stephanie Shipp, Director of the ATP Office of Economic Assessment, John Nail, our primary contact, Prasad Gupte, Janet Brumby, as well as Deborah Rincon in the contracts office, who all patiently and diligently worked with us to make this study possible.

In today's global marketplace, companies face intense competition and increasingly sophisticated consumer demands. Combined with improvements in transportation, communications, and the global development of technology and manufacturing, these trends make for an increasingly competitive global manufacturing environment.

In an effort to respond to these uncertainties and take advantage of the innovativeness and flexibility of small firms, large Original Equipment Manufacturers (OEMs) have not only outsourced the production of components, they have also begun to outsource design, engineering, and technology development to their suppliers. Therefore, if we want to understand the strength and technological capacity of our economy, we must understand that the locus of innovation lies within manufacturing networks – spurred and nurtured by the capabilities of small and medium-size manufacturers (SMMs) – and that these networks compete with other OEM-SMM networks from all over the world.

To better understand manufacturing innovation trends and their implications for federal policy, NIST's Advanced Technology Program (ATP) asked NACFAM to take a fresh look at the changing nature of product development within manufacturing supply chains. Specifically, we asked: as the global marketplace becomes increasingly competitive, how do OEMs work with their suppliers to develop new products and processes? This study outlines the major stages of a "generic" product development process, the design and evolution of supply chain management practices, various strategies for involving suppliers in cost reduction, technology development, and the overall product development process. The report also makes several policy recommendations that seek to address emerging challenges.

THE REPORT VALIDATES AND IS BASED UPON THREE IMPORTANT ASSUMPTIONS:

- The investment and outsourcing decisions of large multinational manufacturing companies have tremendous consequences for the strength and vitality of both regional and national economies.
- At the heart of sourcing are the efficiency, viability and – most importantly – the innovativeness of suppliers, both existing and potential.
- OEM-supplier transactions occur in a policy environment that can either discourage and inhibit or cultivate and sustain the long-term performance of the overall manufacturing network.

Product development is an interdisciplinary process of coordinating various functions within an enterprise to develop, design, and commercialize a new successful product. Most large manufacturing firms employ a formal management process based on a stage-gate model: a series of project mileposts or "gates" in the course of the product development project. While some companies are employing different versions and models, all of the firms in our interviews employed stage-gate in various forms.

Supply chain management has evolved over the course of decades. While supply chain management began as a low-visibility, low-prestige "purchasing" function within companies, it has become a sophisticated core competence for many successful manufacturers. This evolution has its roots in outsourcing – defined as the delegation or "contracting out" of an internal company operation to an external company in order to reduce costs, improve quality and, more recently, bring in new innovative ideas.

Early literature on supply chain management, such as *The Machine That Changed the World*, focuses on the automobile industry and illustrates that American OEMs typically treated supplier purchases as "arms-length," often adversarial, transactions. This stands in sharp contrast to many Japanese manufacturers that emphasize close, long-term OEM-supplier relations. The Toyota Production Systems (TPS) is the most well-known of these management techniques and is often cited as best practice for encouraging long-term, collaborative supplier relationships.

Research shows that the outcomes of these closely managed relationships are continuous improvement in quality, cost reduction, and faster production (and product development) times. While many American OEMs have attempted to implement "Just-in-time" or "Lean" supplier strategies (which are derivatives of TPS), the challenges to successfully doing so are numerous and include misaligned OEM incentives between cost reduction and the formation of collaborative relationships.

While companies must manage their supply chains, they are also faced with the task of developing new technologies as an input into the overall product development process. Spurred by antitrust deregulation and increasing emphasis on near-market research, companies began to look outside their organization for new ideas and technologies. This began through "formal" research joint ventures (RJVs) with other large OEMs with the resources to conduct large levels of R&D. Furthermore, ad hoc partnerships emerged between OEMs and their suppliers, often through relationships between executives or R&D departments as opposed to supply chain managers, tapping into unique competencies embedded in both the manufacturing and relational aspects of the supplier. And though many company executives understand the value of the innovative capabilities of their suppliers, they spoke of how their company struggled with the best way to find, establish, manage, and cultivate these "higher-value-added" relationships.

All of the firms that participated in our study employ supplier segmentation strategies, dividing suppliers into four or five-tiered classifications, ranging from "strategic partner" to commodity classifications. While the definition of a commodity supplier seemed clear, responses varied significantly when it came to the partner category. In follow up questions, respondents admitted that this was an indication of a broader "conflict" between internal supply chain management strategies that emphasize cost reduction and the imperative for innovation and rapid product development. In other words, while involving suppliers in the product development process can be a powerful competitive advantage for OEMs, there exists significant uncertainty about how best to involve individual suppliers especially given competing and conflicting internal policies and practices.

Different strategies exist to involve suppliers in product development, including what we term "reactive" and "proactive" integration strategies. OEMs using a reactive integration strategy rely on suppliers to introduce new ideas and innovations to the OEM, and have developed technical competencies within their purchasing departments in order to "review and judge" the applicability of these innovations to the end product. OEMs employing proactive integration strategies direct substantial resources in order to understand the innovative capabilities of their suppliers while concurrently pursuing targeted high-risk partnership investments to develop new technologies to enhance the capabilities and performance of the final product. In Chapter Three we explore proactive integration approaches long taken by Lockheed Martin's Advanced Development Program (ADP) – or "Skunk Works."

Boeing's current efforts to design, develop, and build the new 787 Dreamliner is a new product development effort that pushes the boundaries of collaboration, based on the technological capabilities of its suppliers. For example, supplier selections for the airframe were based on the capability of a supplier to manufacture carbon fiber composites.

While Boeing's integration strategy was the most all-encompassing among our OEM respondents, all OEMs interviewed recognized the need for increased supplier integration; in so doing all are aware that they face challenges specific to collaboration. These challenges include: internal OEM cost-reduction strategies, internal coordination challenges, misaligned incentives or strategies, inadequate technical and collaboration training among OEM personnel, staff turnover, and, for defense firms, Federal Acquisition Regulations. However, OEM respondents most often cited supplier capability as the largest barrier to the collaborative involvement of suppliers in product development. According to OEMs these consist of technical capabilities to "understand, at a minimum, the system to which they would be supplying, not to mention the complete platform." The confluence of these factors, along with internal structural challenges within OEMs, impacts the performance and competitiveness of the entire manufacturing network.

THIS REPORT IS PART OF A BROADER NACFAM SUPPLY CHAIN INITIATIVE THAT WAS UNDERTAKEN TO FULFILL THREE SPECIFIC OBJECTIVES:

- Identify impediments to achieving a competitive network-centric manufacturing environment.
- Develop a total solutions package where each stakeholder is identified together with their value proposition.
- Spur diverse public and private stakeholders to work together to achieve a multi-tiered network-centric manufacturing capability (see Figure 1).

STRATEGIC INTENT & FIRST PRODUCT

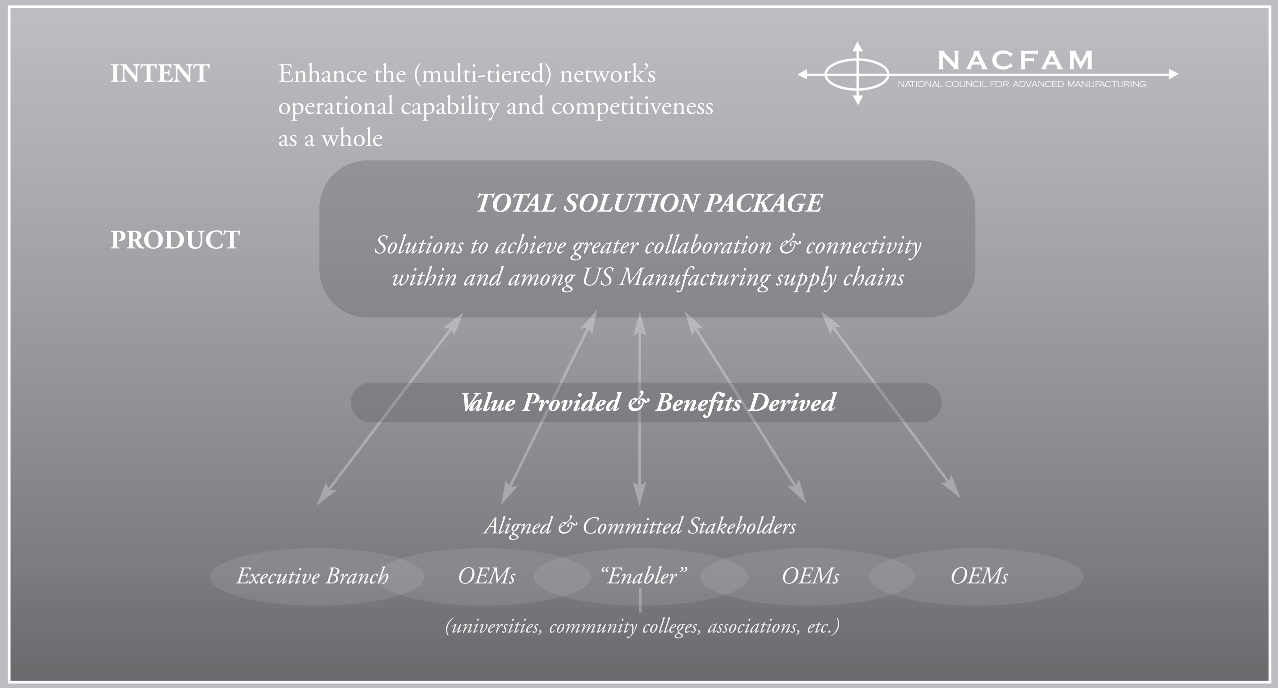


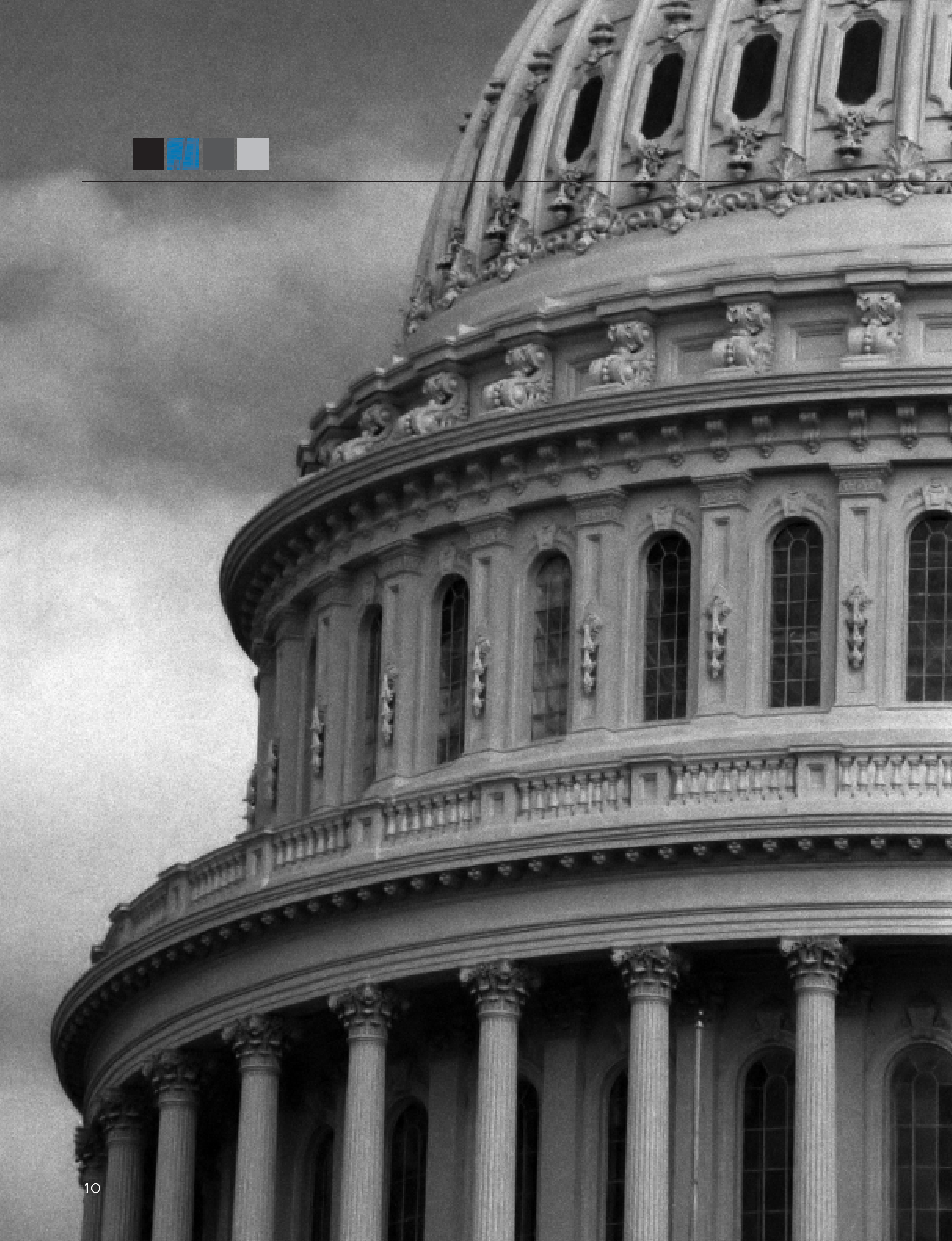
Figure 1

OEM-supplier product development relationships occur in a policy environment that can either discourage and inhibit or cultivate and sustain the long-term performance of the overall manufacturing network. The findings from this report not only support the fact that manufacturing is increasingly network-centric, but also show that the increasing need of OEMs to find and more closely integrate suppliers into product innovation necessitates a national networked infrastructure which supports the overall performance of these networks.

THE CREATION AND DEPLOYMENT OF A ROBUST NATIONAL INNOVATION INFRASTRUCTURE MUST INCLUDE:

- Efforts to pragmatically maximize the return on public investment for programs and services that are currently written into law;
- Efforts to focus these services and others on building innovation capacity within SMM's with substantial input from OEM customers;
- A broad effort to maximize the return on the country's unrivaled pool of public and private R&D investments by understanding how R&D can be conducted in a more "purpose-driven", manner and how resulting (and other) technologies can be better diffused to SMMs, closely coordinated with the deployment of Lean and other process improvement strategies;
- A stable funding structure isolated from the yearly Congressional budget debates through the adoption of a small funding "tax" on agency SMM outreach budgets and – for technology transfer – R&D budgets, similar to the Small Business Innovation Research (SBIR) Program.

SMMs are at the heart of American competitiveness, yet their role in our economy often goes unnoticed. It is their role – their efficiency, viability, and innovativeness – that increasingly drives sourcing decisions from OEMs and success of the overall economy. We must recognize the need for a "total solutions package" response for their rapid competitive transformation (what one OEM respondent called "help[ing] to move suppliers up the value chain"). One realistic solution to this challenge lies with the development and deployment of a robust nation-wide innovation infrastructure that enables U.S. manufacturing networks to rapidly adjust to the increasing enterprise-wide need for innovative new components and technologies in the context of the overall product development process, and therefore remain competitive in the international marketplace.



Introduction

Manufacturing has long been a critical element in the security and economic well-being of the United States. It is a source of revolutionary new technologies, well-paying jobs, and a primary driver of productivity. Over the past several years, manufacturing has received a great deal of attention from the popular press, much of it focused on the automobile industry, plant closings and layoffs.[1] Part of this less-than-positive media attention has focused on the often-confused, but related, terms "outsourcing" and "off-shoring." Outsourcing is the delegation or "contracting out" of an internal company operation to an external company in order to reduce costs, improve quality, and – more recently – infuse the integrator's products with innovative ideas. Off-shoring typically refers to the transfer of outsourced work to another country, or it may separately refer to the transfer of work to a foreign location within the same company.

The publicity that manufacturing has received does not paint a complete picture with regard to the current state of manufacturing; many manufacturers remain competitive, strong and productive. The data show that between 1977 and 2001, manufacturing output, measured in 1996 constant dollars, came close to doubling, while the real output of full-time workers more than doubled during the same period. While it may not be readily apparent, the third and fourth quarters of 2005 were, adjusted for inflation, the most profitable since the second quarter of 1997 – the solid boom year of late 1990s.

Furthermore, while foreign competition may account for a small fraction of the job loss in manufacturing, much of the contraction in manufacturing employment is the result of rapid productivity growth, especially compared to the service sector.[2]

This is not to say that there are not substantial competitive challenges in the manufacturing sector; profitable, well-run companies coexist with others that may not be in business in two years. However, what we as a nation must grasp is that the economic health of manufacturing is not necessarily measured by number of jobs that exist in the sector. In fact, manufacturing employment is declining in some of the most rapidly growing economies in the world, including South Korea, Hong Kong, Taiwan, and even in some industries within the Chinese economy. As Josh Whitford wrote in *The New Old Economy*:[3]

> Efforts to retain the remaining core of good-paying manufacturing jobs (and I would add manufacturing capability and capacity) must be based on a real understanding – neither sugarcoated, nor despairing – of what is possible in the high-wage world, of the feasible and the desirable in a world of global competition, short product cycles, and relatively unstable demand.

Understanding this complicated picture can help industry, government, and education leaders makes choices based on a clear understanding of how firms, the drivers of economic activity, are adapting to the international competitive environment. For large firms, outsourcing has been a necessary component of corporate strategies to cut costs and reduce overhead – often referred to as downsizing and restructuring – that began *en masse* during the 1980s and 1990s in response to international competition.[4] However, successful firms have not only cut costs, they have also focused on becoming more innovative.

At its core, innovation is the "transformation of insight and technology into novel products, processes, and services that create new value for stakeholders, drive economic growth, and improve standards of living."[5] While internal research and development have been a traditional source of ideas for firms, it is the development of new products – from the interpretation of market needs, ideation, and technological possibilities to design and engineering and manufacturing and distribution – that lies at the heart of innovation.

Companies also look beyond their boundaries for innovation. Increasing competitive pressures and the relaxation of antitrust regulations have allowed original equipment manufacturers (OEMs) to form joint research partnerships. Companies have also begun to take advantage of the innovation and flexibility of companies outside "their four walls," either the very firms to whom they have been outsourcing or potential new partners. Outsourcing is no longer just about reducing costs; it is also about the search for new, economically useful ideas and their manufacture.

Studies show that one of greatest barriers to innovation is a firm's inability to coordinate multiple and varying resources within its boundaries. This coordination challenge is intensified as firms are also charged with coordinating the innovative activities of firms with whom they work. In the most dramatic cases, OEMs must coordinate the disparate operations across the multiple functions of multiple firms, in effect attempting to create a manufacturing innovation network. Therefore, if we want to understand the innovative capacity of our economy, we must understand that the locus of innovation lies within manufacturing networks, spurred and nurtured by OEMs, suppliers – often small and medium-size manufacturers (SMMs) – educational and research institutions, and public-sector policies and programs; what we call "network-centric manufacturing." Collectively, these innovation networks compete with other networks from all over the world and, if successful, will generate wealth and prosperity for both firms and the regions in which this economic activity occurs.

This report summarizes a study undertaken at the request of the Advanced Technology Program (ATP) housed in the National Institute of Standards and Technology (NIST). The report seeks to explore and understand how manufacturers develop products from idea to manufacture, including the development of technology, and the evolving role of their suppliers in this ongoing endeavor. There are three points that, regardless of what other things you take away from this report, should be emphasized and repeatedly referred to in subsequent discussions of its implications. The first is that Thomas Friedman in his book *The World is Flat* was right: large multinational companies – in our case manufacturing firms – make investment and outsourcing decisions every day that have tremendous consequences for the strength and vitality of both regional and national economies. Second, at the heart of these decisions is the efficiency, viability, and – most importantly – the innovativeness of their supplier partners, both existing and potential. Lastly, these transactions occur in a policy environment that can either discourage and inhibit or cultivate and sustain the long-term performance of this network-centric enterprise of OEMs and their suppliers. It is these networks, including their relationship with public policy, that innovate, create wealth, and generate prosperity for the United States.

CONTEXT OF THE REPORT

This report is exploratory in nature and emphasizes the strategies and management practices of large manufacturing firms. However, NACFAM is a manufacturing research and education organization and, to this end, must also examine how these trends impact public policy — the "what does this mean" factor. While the U.S. government does not and should not have control over the internal operations of large manufacturing firms, our governing institutions must develop the capacity to understand in detail competitive industry trends. It is the relationship between these trends and the mechanisms of governance – policies, programs, incentives, and regulations – that collectively account for national competitivenes. It is our hope that this report contributes to this understanding.

For purposes of this report, we classify manufacturing firms as either OEMs or suppliers. "OEM" is a common term in manufacturing referring to a large company that typically sells its products to retailers or, in some cases, markets directly to the customer. The term "supplier" refers to a company that sells what it makes to another, typically larger, manufacturer. While large companies may be both OEMs and suppliers (for example, Raytheon supplies aircraft components to Lockheed Martin as well as selling directly to the government) special attention is paid to the role of small and medium-size manufacturers (SMMs) and their role as suppliers. While these terms are used generally, it should be noted that they are also simplifications of a very complicated industrial landscape.

A number of factors help determine how a manufacturing firm structures its product development process. These factors include firm size, history, industry, the technical complexity of its products, and its underlying product architecture. With a few exceptions, this report examines product development processes in companies that are engaged in heavy manufacturing and whose products are engineered, discrete, and comprised of many components with differing levels of sophistication. For these firms, technology development, outsourcing, supply chain management, and systems integration are vital parts of their product development processes. In addition to these characteristics, firms participating in our study share two specific similarities: multiple component "Clockspeeds" and high component complexities.

Clockspeed is a concept introduced by Professor Charles Fine that distinguishes between fast- and slow-changing industries.[6] Fine describes Clockspeed as an industrial analogy to genetics: fruit flies have very short life expectancies and, therefore, species mutations can be observed and studied in a relatively short period of time. However, mutations in larger organisms such as whales, for example, take longer to observe. Fine applies this generational concept to the study of industrial organization, positing that industries, and therefore components, experience different rates of change. For example, the fashion and semiconductor industries "mutate" very quickly based on frequent changes in consumers tastes and rapid technological development, respectively.

The other major similarity among companies participating in our study is what we term "high-component complexity:" a high number of individual parts that comprise a final product. For example, a product with very simple component complexity is Breyer's Vanilla Ice Cream, which is comprised primarily of milk, sugar, and vanilla bean. A laptop is comprised of approximately 400 individual components while a modern automobile consists of approximately 15,000. A large commercial airliner, such as the Boeing 777, lies at the other end of the component complexity spectrum with tens of thousands of unique parts and millions of total parts.[7]

Companies that sell slow Clockspeed, low-complexity products such as soft drinks, ball-point pens, toothbrushes, and socks may employ very sophisticated product development and manufacturing processes. However, we focus on firms with varying component Clockspeeds and high component complexity because of the challenges associated with managing these manufacturing enterprises, the importance of these firms to the overall economy, and the fact that many of these companies are NACFAM members, facilitating access to company representatives. Because of the complex nature of these enterprises, it our hope that important lessons for all industries can be extrapolated from these examples.

Participating companies include: John Deere, DaimlerChrysler, Harley-Davidson, Lockheed Martin Aeronautics, Boeing Commercial Airplane Division, and two other companies that wished to remain anonymous, including a manufacturer of household equipment and one of heavy-duty industrial machinery. In our study, the manufactured product with the lowest component complexity examined during our study is a John Deere lawnmower comprised of a few hundred parts. However, Deere also produces highly complex systems such as combines, large earth-moving equipment, and large engines. The manufactured product with the highest component complexity is the Boeing 787. The product development process for the Joint Strike Fighter, jointly built by Lockheed Martin, Northrop Grumman, and BAE Systems (and their suppliers), is also extremely complex and challenging, reflecting the unique requirements and regulatory nuances of the defense industry.

For each of the companies we studied, there exists a formal management process for product development, such as the Enterprise Product Development Process at John Deere, the Airplane Creation Product Strategy at Boeing, and the Chrysler Development System, that is based on a stage-gate model explained in the first chapter. In all cases the final products of these development systems are comprised of a large percentage of components purchased from suppliers outside the company. Therefore, each of these large manufacturing companies has created and implemented supply chain management strategies. Though product development is an inherently multi-functional process, supply chain management departments have often operated as a low-skilled, low-visibility organizational "silo" that, because of the initial cost-cutting emphasis of outsourcing, has evolved in ways different than the intent of a collaborative, intra-company product development process. This report will discuss the independent evolution of product development and supply chain management, as well as the attempts by manufacturing companies to align the two.

LAYOUT OF THE REPORT

This report is organized into four primary chapters. Following the introduction, Chapter One examines a generic stage-gate product development process and cites examples from our company respondents illustrating different approaches within subsections of the report. Chapter Two reviews the literature of supply chain management as well as various perspectives from our respondent companies. Chapter Three then reviews how companies are attempting to work with their suppliers to develop new products and technologies, again using examples from the literature and our respondent companies. In Chapter Four, we discuss recommendations, review findings from our study as well as specific comments with regard to public policy, and lay out a series of policy recommendations. The appendices include the endnotes, bibliography, and our interview template.

METHODOLOGY

Since its establishment in 1989, NACFAM has sought to inform and promote policies to enhance the productivity and competitiveness of U.S. manufacturing. NACFAM's success is derived from its capacity to convene leaders from government, industry, and educational institutions in a non-partisan, non-adversarial environment in order to broker the intense collaboration required to develop effective policy solutions. NACFAM also has a reputation for well-researched, timely policy work, especially in areas such as technology, supply chain integration, and workforce development. NACFAM leveraged this collaborative philosophy and expertise to undertake this study.

While many insights were gained from this in-depth study, it is only a snapshot of the relationship between product development, supply chain management, and innovation. We do not profess to encompass the complete range of challenges or industry responses in this context, but we hope to help foster general understanding of these trends, limited by the bounds of qualitative research.

Furthermore, the project did not examine elements of contract manufacturing, craft industries, or other commodity manufacturing. However, an attempt was made – in industrial studies dominated by automotive anecdotes – to add diversity by including examples from aerospace, manufactured consumer goods, and the defense industry.

Project findings are based on a simple multi-phase methodology including:

Literature Review and Advisor Recruitment: The first phase of the project included planning and the recruitment of project advisors to enhance NACFAM's institutional expertise and capacity in product development and supply chain integration. Furthermore, NACFAM staff conducted a comprehensive review of the economics, supply chain, product development, manufacturing, and technology development literature taken from books, scholarly journals, periodicals, newspapers, and other media, a listing of which can be found in the bibliography.

Company Interviews: NACFAM staff undertook a series of interviews in order to create an in-depth look at how OEMs are responding to increasingly competitive market conditions; how they are "innovating," specifically focusing on the development of new technologies, product and process development; and, within this context, how OEMs are working with their suppliers. These interviews included more than 70 qualitative and semi-structured interviews from large OEMs in key heavy manufacturing industries, as well as numerous, more informal conversations with experts from other manufacturers and academia.

The interviews were carried out between November 2005 and June 2006 and, in most cases, were scheduled by a point of contact designated by a senior corporate official at the Vice President or Director level. Interviewees included company personnel representing different departments, such as marketing, strategy, technology development, product design, systems engineering, purchasing, manufacturing, and distribution.

Except where noted, all interviewees were granted anonymity. While participant companies were very accommodating with our requests for access, and in fact allowed us to acknowledge their participation, we do not attribute specific examples to specific companies, unless these same examples are publicly available.

Interviews were guided by a simple protocol to ensure consistency and accuracy. This protocol, found in the appendices, was tested and validated by a number of academic and industry experts. While participants helped to validate many of the findings in our literature review, this report does not profess to capture the entire range of manufacturing challenges or industry responses, and is constrained by the limits of qualitative research.

Symposia: A series of policy symposia were attended and convened for the purpose of mapping and distilling the relevant information for the project. These events included:

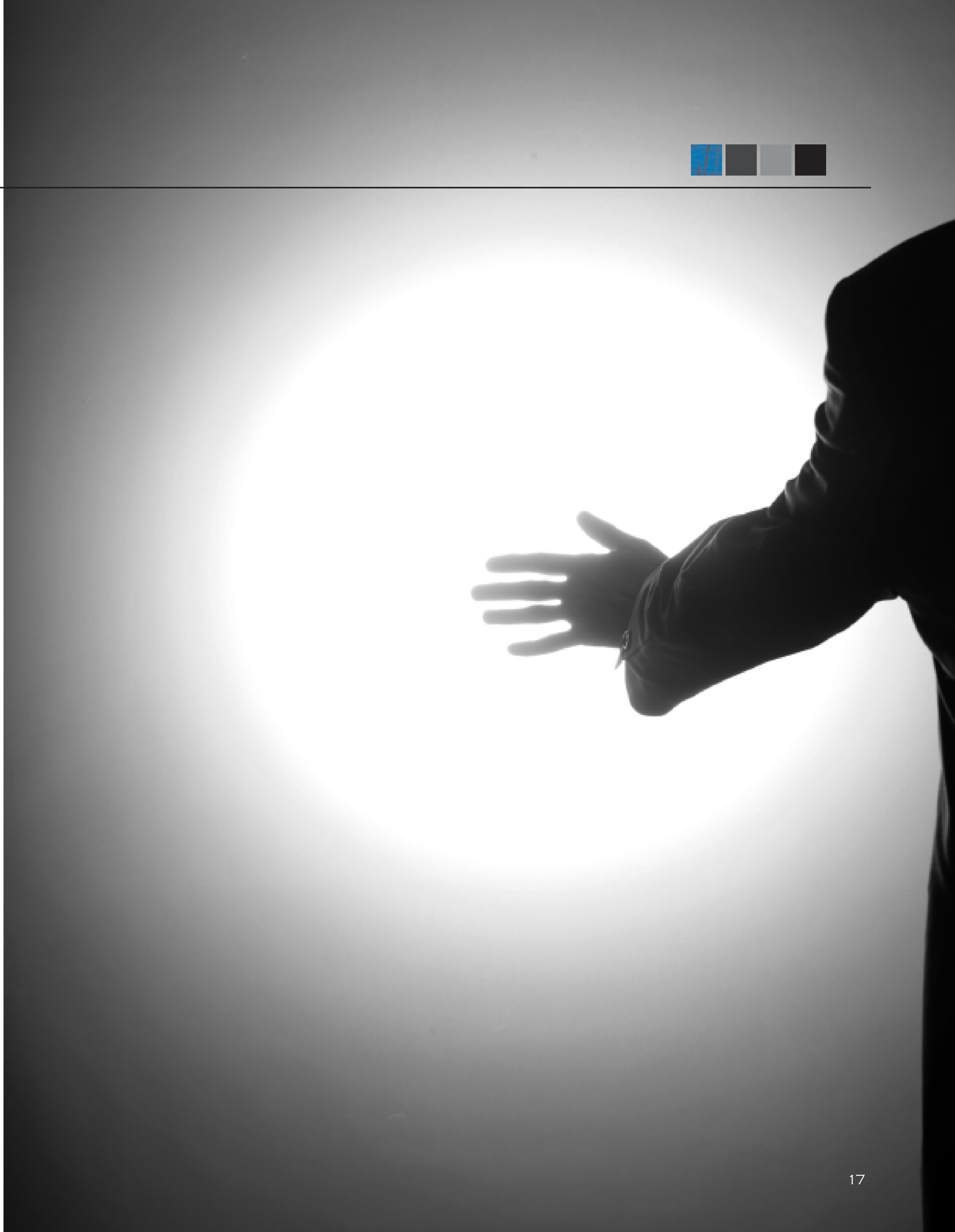
December 3, 2005: Workshop at the Massachusetts Institute of Technology (MIT) with Charlie Fine and David Simchi-Levi to explore management challenges and techniques for Supply Chain Integration.

May 12, 2006: NACFAM jointly sponsored a conference with the MIT Forum for Supply Chain Innovation, convening leaders and experts from industry, academia, and the public sector to examine product development innovation in the supply chain and to validate the findings of the project.

June 28, 2006: Workshop at MIT hosted by Steven Eppinger covering the management of product development projects, including a comprehensive overview of Design Square Matrix (DSM) and Global Product Development.[8]

Forum on Implications for Public Policy: NACFAM hosted a forum during its annual meeting held on June 7, 2006, in Washington, D.C., to explore and understand the policy implications of the project's initial findings. The session was attended by the NACFAM Board, principal NACFAM members, and other guests including Dr. Warren DeVries, Director of Engineering and Manufacturing Innovation at the National Science Foundation, Dale Hall, Director of the NIST Manufacturing Extension Laboratory, and Zach Zacharia, Assistant Professor at Texas Christian University. The findings and recommendations included in Chapter Four have been largely derived from the policy-related comments of our industry respondents and the relevant discussions during this meeting.

External Validation and Review: NACFAM invited several experts, including Paul Ericksen, retired supplier development lead at Deere and Company, Josh Whitford from Columbia University, and Gary Conley from Techsolve, among others, to review the contents and comment on the report to ensure accuracy and for external validation. A copy of these comments may be obtained upon request. Company points of contact were also sent a prepublication draft for review and comment. Their comments were incorporated based on the judgment of NACFAM staff.



CHAPTER ONE: THE PRODUCT DEVELOPMENT PROCESS[9]

For at least the past thirty years, pundits, policymakers, and researchers have decried the need to improve innovation in the United States, often without a full understanding of the firm-specific, industry-specific, or policy nuances associated with manufacturing competitiveness. At the heart of manufacturing competitiveness – and the success of individual companies – is the ability of a firm to understand the needs of its customers and quickly turn these needs into products that can be produced at low cost. And while challenges to U.S. manufacturers are myriad, it is the confluence of many of the aforementioned factors that collectively account for a firm's eventual success or failure. The purpose of this section is to explore one of those key factors: product development.

Professors Karl Ulrich and Steven Eppinger define product development as a "set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product." They also define the product development process as "the sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product." Product development, by its nature, is interdisciplinary and requires extensive coordination among most, if not all functions of the firm and increasingly, as we will later examine, other firms.

Firms manage these processes with formal strategies and techniques in an effort to maximize coordination and efficiency, and minimize time to market. Most manufacturing firms employ a formal product development template based on what Robert Cooper calls a "stage-gate process:" a series of project mileposts or "gates" in the course of the product development project.[10] This section will examine a "generic" stage-gate product development process and discuss examples taken from participating companies in order to understand just how OEMs are managing their product development process and how this relates to their success.

A "GENERIC" PRODUCT DEVELOPMENT PROCESS

In a generic version of a product development process there are six phases, including planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up. Companies may differ in the employ and organization of specific product development steps but most large manufacturing firms have adopted derivations of this structured product development method in an effort to aid in coordination and communication, quality assurance, planning, performance management, and evaluation. All of the manufacturing firms participating in our study utilized a stage-gate -based model for their respective product development processes. Figure 2 illustrates a typical product development process divided into phases.

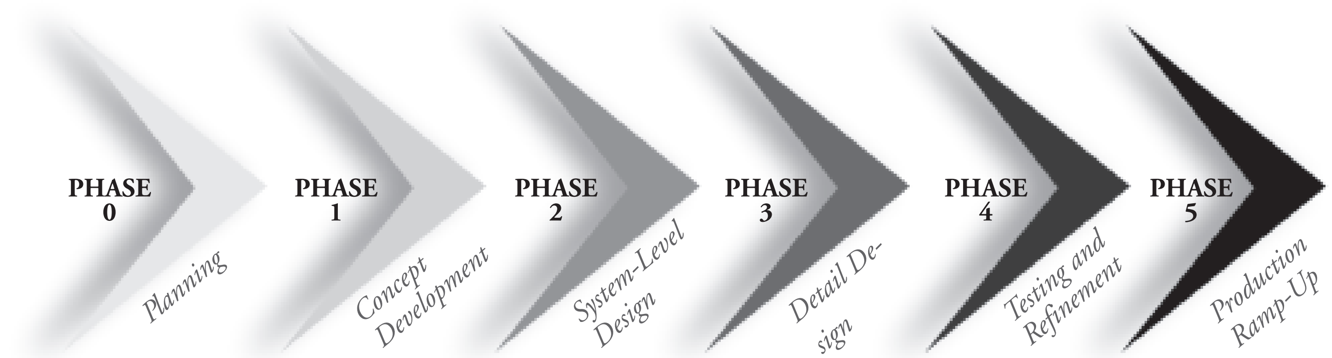
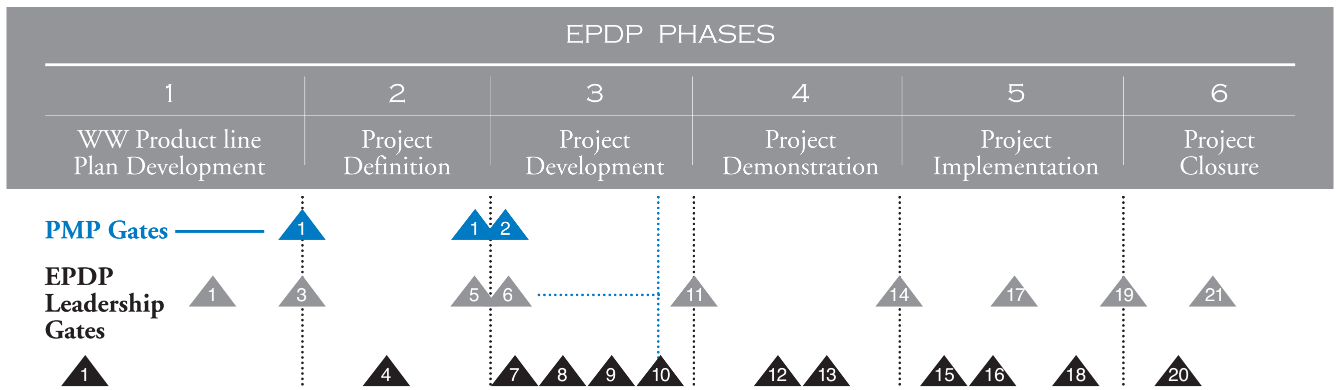


Figure 2

PRODUCT DEVELOPMENT AT JOHN DEERE



1.Start development of a world-wide product line plane
2. Leadership approval of the product line plan
3. Leadership approval of the project charter
4. Feasibility model & supplier intergration plan completed
5. Leadership approval of the project plan
6. AFE Approval
7. Lauch project team
8. Release from electronic build completed
9. Full electronic build completed
10. Release for physical build completed
11. Leadership approval to start physical builds
12. First physical build completed
13. Product & process verification (pre-build/unsold machines)
14. Leadership approval for production launch
15. Production start (limited or full build of sold machines)
16. Product & process verification
17. Leadership approval to ship
18. Achieve planned full production rate
19. Leadership approval to move into Phase 6
20. Begin redeployment of team resources
21. Leadership approves project closure

PHASE ZERO: PLANNING

In product development, Phase Zero (or the planning phase) precedes the project approval and launch of the product development process. It is typically a scoping exercise designed to identify the type of product development projects that will actually be undertaken. Deliverables might include a project mission statement, business goals, key assumptions, and constraints. Phase Zero is heavily influenced by a firm's capability to understand the market in which it operates, translate these observations into a product strategy, and effectively transition into the concept development phase.

A marketing executive usually leads Phase Zero and is responsible for guiding and facilitating the discussions of a multi-disciplinary team. The job of this team is to determine the mix of fundamentally new products, platforms, and derivative products, how these products relate to each other, and how these products compare and relate to other products on the market. Four possible projects include[12]:

New product platforms: This project would represent a major development effort to create a new family of products based on a new, common platform addressing familiar markets and categories. For example, an automobile maker may seek to create a new common platform on which several familiar product lines may be built: a family car, a sport coupe, and a wagon.

Derivatives of existing product platforms: This project would extend existing product platforms to address familiar markets. For example, the introduction of a wagon version of a current car line on the same platform.

Incremental improvements to existing products: This project would add to or modify features of an existing product line on its existing platform to keep it current and competitive. For example, successive models of the Boeing 737 from the 100 model first released in 1968 to the 200 model, also introduced in 1968, to the current next-generation/900 model introduced in 2001.

Fundamental new products: These projects seek to create radically different products or production technologies and involve the most risk but the long-term success of a company may depend on them. The Blackberry handheld email device, the first Chrysler minivan, and the first successful commercial jetliner might all be considered fundamentally new products, though the level of "newness" may differ relative to the maturity of the industry.

For many companies, the planning phase serves as an opportunity to test and demonstrate new technologies that would add capability and functionality to products under development. In other words, a new technology that has been under development or that was developed by a supplier becomes a major factor around which a product concept will be developed in Phase One. The planning phase is also an opportunity for many companies to incorporate supply chain strategies as they relate to product architecture, which we will discuss in subsequent sections.

PHASE ONE: CONCEPT DEVELOPMENT

During the concept development phase, "the needs of target markets are identified, alternative product concepts are generated and evaluated, and one or more concepts are selected for further development and testing."[13] Phase One begins with identifying the needs of the customer by observing the use of similar products in the field, holding focus groups, talking to product users, conducting interviews, and analyzing marketing datasets to establish customer needs, often in the form of a problem.

Once customer needs have been established, target specifications can be created to represent how the product must function in order to meet those needs, in the language of that particular customer. Ulrich and Eppinger recommend an analytical approach to defining target specifications by using both a metric and a value for each of the identified needs. The example that they use, "average time to assemble" is a metric, while "less than 75 seconds" is the value of this metric. Their four-step process for determining target specifications includes[14]:

1 Prepare list of metrics.

2 Collect competitive benchmark information: benchmarking of competitive products.

3 Set ideal and marginal acceptable target values.

4 Process the results and make tradeoffs reflective of the overall product strategy identified in Phase Zero.

In our study of the product development process at Lockheed Martin Aeronautics, the creation and setting of product specifications is a lengthy, iterative process with their primary customer, the Department of Defense (DOD). Target specifications for a new aircraft might include payload (bombs, food, soldiers, or other supplies); effective range (how far the aircraft will be capable of flying); and performance (speed and maneuverability). While basic product specifications are established early in the development process, other desired product performance characteristics may be purposely delayed. For example, specifications for technology-intensive products such as avionics and weapons systems may be delayed until the concept matures, taking advantage of subsequent advances in technology.

The generation of concepts is an exploration of potential ideas that may meet the needs of the customer. Ulrich and Eppinger outline a five-step approach to concept generation[15]:

Clarify the problem: This step helps develop an understanding of the issue and facilitates breaking the problem into its sub-problems or key customer needs. Development teams may choose to prioritize and focus on sub-problems that are most critical to the success of the product.

External Searching: Searching involves a survey of resources external to the company in order to find a solution to the overall problem and/or sub-problems identified during the first step. Searching occurs throughout the process and involves information gathering, including literature and patent reviews, interviews with lead users, expert consultation, and industry and supplier collaborations such as road mapping and joint ventures.

Internal Searching: Many companies also have internal resources that may be harvested to provide solutions to the problems and sub-problems identified in the first step.

Concept Selection: This is the process of systematically evaluating concepts and their capacity to meet the needs of the customer. Furthermore, concepts may be evaluated on their relative performance during testing.

Concept Testing: A process verifying that customer needs have been met and to assess the potential market for the product (may be terminated if response is poor).

During our interviews, many individuals described the importance of a product concept "package": a set of deliverables that would go to a team with the authority to select concepts for further consideration and research. These packages include sketches or artist-rendered illustrations of the concept, approximate descriptions of the technology, working principles, and in some cases computer-generated "cartoons" demonstrating how, based on the target specifications, the concept might perform. Others mentioned the importance of the "business case" for the concept or how the concept relates to the products of a competitor. Outcomes from the review of a product concept package may include approval ("how fast can we get this into production?"), rejection ("we are not interested in this idea"), cancellation ("this will not work…we do not want to see this concept again") and, most common, recommendation for further analysis ("keep looking at this" or "go back and see if you can make the numbers work").

CONCEPT GENERATION AND THE EVOLUTION OF THE BOEING 787[19]

With low complexity products, concept approval may be a relatively simple process involving a small product development team. However, for large-scale platforms requiring millions or even billions of dollars of capital investment and thousands of people employed on single development projects such as that of a new commercial airplane, the concept generation and approval process is much more elaborate and can last over the course of several years.

When Boeing was developing a new product concept during the late 1990s, it sought to focus its efforts on a 180 to 300 seat airplane to replace the 757 and 767, compete with the Airbus A330-200, and complement a Boeing line that includes the next generation 737 and 747X. Furthermore, Boeing wanted its new concept to reflect the strategic belief that future air travel would rely less on the traditional hub-and-spoke airline system and more on a "fragmented" route structure connecting international city pairs that had never before seen service. This approach is in sharp contrast to the strategic intent of the Airbus A380, designed to move as many passengers as possible between large "mega hub" airports such as London's Heathrow and New York's John F. Kennedy Airport.

(Continued on page 23)

Successively dubbed "Project 20XX," "Project Glacier," and later the "Sonic Cruiser," Boeing's initial aircraft concept was an unconventional configuration: a 767-sized aircraft with aft-mounted engines and swept wings with a range of 8,000 nautical miles or more. The Sonic Cruiser concept was designed for faster travel, flying at speeds between Mach 0.95 and 0.98, with operating costs similar to the 767-300. However, Boeing was forced to rethink this concept shortly after its public release due to the terrorist attacks on September 11, 2001, the subsequent downturn in the global airline industry, and the related cancellation of Concorde flights by Air France and British Airways in 2002.[20]

A separate team had been working to develop another concept, one dubbed "Project Yellowstone," since at least 1998. Yellowstone began as part of project 20XX as an effort to apply many of the same advanced manufacturing, design, and systems technologies developed for the Sonic Cruiser to a more conventional jet design. Faced with the need to choose between the Sonic Cruiser and the evolving Yellowstone concept, Boeing decided to involve its customers in the concept selection. When offered three versions of the Sonic Cruiser concept, along with what was labeled the "Super Efficient" Yellowstone design, the airlines chose the latter based on the concept's promised fuel savings, reduced maintenance costs, and commitment to substantially improve the experience of the flying public.
On January 2003 Boeing committed to further developing and building the Project Yellowstone concept, renaming it the 7E7, emphasizing the project's focus on efficiency, economy, and the environment.

PRODUCT ARCHITECTURE

Concepts for some complex products may take years to develop and necessarily include discussions during the concept development phase. Product architecture is defined as the way by which the functional elements (or component systems) of the product are arranged into physical "chunks" and the way in which these chunks interact.[16] It can be thought of in both functional terms – the individual operations of the chunks that together account for the overall performance of the product – and in physical terms, including the parts, components, and subassemblies that ultimately perform the product's functions, commonly organized into physical chunks. The arrangement of the product functions can be further divided into modular and integral architectures. Karl Ulrich distinguishes between an integral architecture that might feature[17]:

- Components that perform many functions
- Components that are in close proximity
- Components that are tightly synchronized

While a modular architecture features separation among a system's constituent parts, whereby:

- Components are interchangeable
- Components are individually upgradeable
- Component interfaces are standardized
- System failures can be localized

The product strategy initially identified in Phase Zero helps determine whether or not the product architecture is fully defined during the Concept Development Phase or during Systems-Level Design. Product architecture may be defined early if the product concept is a derivative of existing company products or platforms, or if the concept is defined as an incremental change to an existing product. With early-established physical specifications and product architecture, concept development can focus on individual product features, improving systems performance, technology updates, and final product fit and finish. However, when the product is the first of its kind, concept development is generally concerned with the basic working principles and the technology on which the product will be based.[18]

Systems architecture may also be defined early in the process based on the need to create "unique selling points" (USPs) in order to penetrate new markets. For example, customers for both military and commercial aircraft require platforms designed with modular architectures that allow for periodic technology upgrades for fast Clockspeed components. Other components may require a modular architecture so that worn out or depleted parts such as a razor blade or printer cartridge may be replaced. Product architecture for more mature products may place greater focus on "downstream" issues such as supply chain efficiency, product variety, or facilitating ease of assembly during the manufacturing process, otherwise known as Design for Manufacturing (DFM). Finally, product architecture may seek to accommodate emerging end-of-life considerations for the product, including its disposal, reuse, and recycling.

The companies we interviewed have different processes for generating and approving product concepts but all share key elements. One company in our study tasks a senior level product strategy team with "finding the right products in the right consumer segments" supplemented by a consumer trends group responsible for "predicting customer needs five years out." Comprised of executives from product development, design, marketing, purchasing, and finance, the team meets every three weeks to discuss ongoing competitive analyses, generate concepts, review proposed concepts from other parts of the company, and review concepts which were recommended for additional research or study. After review, the group is responsible for a "consensus recommendation" of which concepts should approved, which is then presented to the company's CEO for final approval.

One staffer of the product strategy team explained the process:

> Ideas come from different parts of the company … but, in the past, most of our designs came from our design studio … we were very designed focused. While the studio is still an important source of our ideas, we study our concepts a lot more … rely on market research. We have had successful products using this approach but we had a lot of successes using the past approach as well … we have also had our dogs. But overall we are becoming more and more analytical in the way we approve concepts.

Another company we interviewed attributed the company's winning concepts to the work of a handful of designers and one designer, in particular:

> The design of all of our products for at least the past 25 years can be traced back to [this man]. He is the creative genius and architect of our product. He pretty much leads and we [manufacturing] follow.

CHALLENGES TO CONCEPT DEVELOPMENT

Most senior managers with whom we spoke related a product's success or failure to the Concept Generation phase. Most expressed that a primary challenge to concept generation was articulating the business case for a product. One manager told us:

> We have a lot of talented, creative people here that operate from the gut … from the heart … but then translating these ideas into the bean counter's world is a real pain. More and more our company is emphasizing what the accountants [and stockholders] want, but our success has been built on what the customer wants.

Conversely, many managers thought that their product concepts did not have enough of a business case:

> We just didn't have the market figured out.
> We didn't know if it would fly or not and it did.
> It was a product ahead of its time. It has definitely not met sales expectations but it is a really good product and we think that it will begin to take off in another five years once people have discovered that we actually build [this product].

All companies talked about the "different language of marketing" and that the needs of the customer were often difficult to interpret and understand, including when working with the Department of Defense:

> We have marketing people in Washington whose job it is to understand the needs of the customer. These are people with extensive technical backgrounds and we still have difficulty trying to understand them … they are often in the middle between our customer and our designers … we affectionately use the term 'marooned' to describe their situation.

PHASE TWO: SYSTEM-LEVEL DESIGN

System-level design is a general description of the break down of a concept into its component chunks so that they may be designed and manufactured. In some companies, system-level design often includes the approval of a concept, while in other instances, it begins after a concept is selected and approved. In any case, once a concept is chosen, the product architecture is typically formalized, and product development teams are formed based on the division of the product into its component systems, layered sub-systems, and respective components. Each team is responsible for the technical performance characteristics of each system and its components.

In the aerospace industry, these product development teams are often known as Integrated Product Teams (IPTs). During the Concept Development Phase, outer mold lines – an outline of the shape and skin of the airplane – are generated during a process called "sizing the vehicle." IPTs are organized based on the categorization of the aircraft into major systems with ultimate responsibility resting with a strong project manager, typically called the "Air Vehicle Lead." Major representative systems teams include: electrical systems, hydraulic systems, avionics, major structures, detailing, interiors, propulsion, aerospace support, technology, and services, with the addition of weapons systems for defense aircraft. Furthermore, there are support IPTs that work among all teams and supervise the design and integration of the overall aircraft, including stress analysis, plumbing, thermodynamics, and structural design. Major systems teams are, in turn, broken into subsystem teams that are responsible for designing the specific components in these systems and subsystems.

For another company participating in our study, the structure of its product development teams depends on the complexity of the product being developed. For the company's large products, designers are assigned to the development of one large platform and may remain with this team for years, specializing in hydraulics, electronics, structures, or cabs. They are joined on this team by personnel from Quality, Supply Management, Customer Support, Manufacturing, Engineering, Finance, and Testing. For smaller, less complex products, members of product development teams have considerably more responsibility for different platform functions as well as responsibility for multiple products.

For product development teams of all sizes, a cost model for the final product is developed during the System-level Design Phase by working with designers, supply chain managers and suppliers to draft a bill of materials (BOM), which is an overarching estimate of fabrication costs and purchase prices for each component in the product. At this point key suppliers are identified, especially if they possess a unique component or technology, or, in cases of modular outsourcing, if they are responsible for the manufacture of a complete system. For example, a designer from a heavy equipment manufacturer spoke of her company's move to outsource "the entire design and manufacturing of a product's control system" where "the interfaces and performance standards are well-defined but it is up to [the supplier] to determine how to best design and build the system…which is bid out as a single module at a single price."

For mature industries with many relatively slow Clockspeed components, OEM managers often have a good idea about how much a part will cost to manufacture and so may not involve suppliers in this step. However, for new platforms or for components utilizing new technologies, the creation of the BOM becomes more iterative because "we (the OEM) are learning at the same time as the supplier is developing their new technology and this is subject to many different variables." Since the BOM is a "best estimate" it is useful in creating a cost range for new products, but not necessarily one precise price. Teams developing complex products containing hundreds or thousands of parts will generally not be able to include every part in the BOM but the team will list the major components and subsystems and place bounds on their costs based on past experience or the judgment of suppliers.

As systems and sub-systems are designed and a BOM is developed, designers and engineers must make trade offs to balance performance characteristics between and among systems. For example, DOD may, during the development process, ask that a new fighter be capable of carrying additional payload as opposed to an initially agreed-upon specification. Increasing payload adds more weight, which in turn may increase the need for more thrust, which may add the need for different engines and more fuel, which may add additional weight. Too much weight may impact the desired speed performance requirements, and so on.

Ulrich and Eppinger use an automobile to demonstrate the trade offs that must occur between systems and therefore performance metrics such as fuel economy, acceleration time, and turning radius. System trade-offs are also dependent on subsystem tradeoffs in the body, engine (like torque, fuel efficiency, peak power, etc), transmission, braking system, and suspension, that collectively account for "higher level" systems performance. At some point the engineers must end their trade-offs and agree to a "design freeze," a point in the product design process where all compromises must be stopped so that the product can actually be built. Once a system design is frozen, then the process can continue to the Detailed Design Phase.

Once system-level specifications have been set, project planning begins through the establishment of tools for creation of a detailed development schedule, a strategy to minimize development time, and the identification of resources required to complete the project. Then product development teams perform an economic analysis by building a model to resolve trade-offs among development costs and manufacturing. Plans for final assembly for the production system are usually defined during this time as well.

PHASE THREE: DETAIL DESIGN

Once a system-level design is in place, the detail design phase can begin. This includes the "complete specification of the geometry, materials, and tolerances of all unique parts in the product and the identification of all standard parts to be purchased from suppliers."[21] While the detailed design of components must necessarily follow the design of its respective system, detail design often occurs concurrently with the design of other systems. As components are designed, they are accompanied by drawings or computer files describing the physical properties and specifications of each part, production tooling designs, and other supporting elements.

After detailed designs and their supporting documentation are complete, these packages are can be released to suppliers (or internal manufacturing groups). Suppliers may receive product and component blueprints either in the form of physical blueprints or increasingly through "solid models:" electronic files often in three-dimensional form graphically illustrating the component to be produced. Many times, especially for complex products, suppliers rely on other suppliers to manufacture components for their components and, therefore, these specifications must "flow down" to sub-tier suppliers. In some industries, flow-down may occur many times, resulting in many challenges to the flow of information and correct manufacture of these components. This will be discussed in the second chapter.

PHASE FOUR: TESTING AND REFINEMENT

The testing and refinement stage is where the pre-production version of a product is finalized as preparations are made before its manufacture. Product finalization includes "the construction and evaluation of multiple pre-production versions of the product" typically called prototypes. A prototype is "an approximation of the product along one or more dimensions of interest."[22] Prototypes are classified along two dimensions:

Physical scale: Physical prototypes are tangible models created to approximate the product. Aspects of the product of interest to the development team are actually built into a model for testing and experimentation. Examples include models that look and feel like the product: proof-of-concept prototypes used to test an idea quickly, and experimental hardware used to validate the functionality of a product.

Scope: The second dimension is the degree to which a prototype is comprehensive as opposed to focused. Comprehensive prototypes implement most, if not all, of the attributes of a product. A comprehensive prototype corresponds closely to the everyday use of the word prototype, in that it is a full-scale, fully operational version of the product. A focused prototype only implements one or a few of the product attributes for the sole purpose of exploring its form its performance.

Traditionally, prototypes have been classified sequentially as Alpha and Beta, though more than two versions can exist, depending on their functionality.

Alpha prototypes are tested to determine whether the product will work as designed and whether the product satisfies customer needs.

Beta prototypes are intended to answer questions about performance and reliability in order to identify necessary engineering changes for the final product. Beta prototypes are built with production-intent parts, that is parts with the same geometry and material properties as intended for production but not necessarily fabricated with the actual processes to be used in production. Betas are extensively evaluated internally as well as tested by customers.

A related model used during the testing and refinement phase includes form-only models: non-functioning prototypes – also known as "mules" – designed to evaluate ergonomics, style, and fit.

The primary purpose of a prototype is to learn, model, and establish a proof of concept: a demonstration to see whether or not a concept identified in earlier phases is feasible. Other uses include communication with top management, vendors, partners, extended team members, customers, and investors. During subsequent product development phases, prototypes may also be used for integration. This ensures that components and subsystems work together as expected, as well as satisfying project milestones that demonstrate that a product has achieved a desired level of functionality.

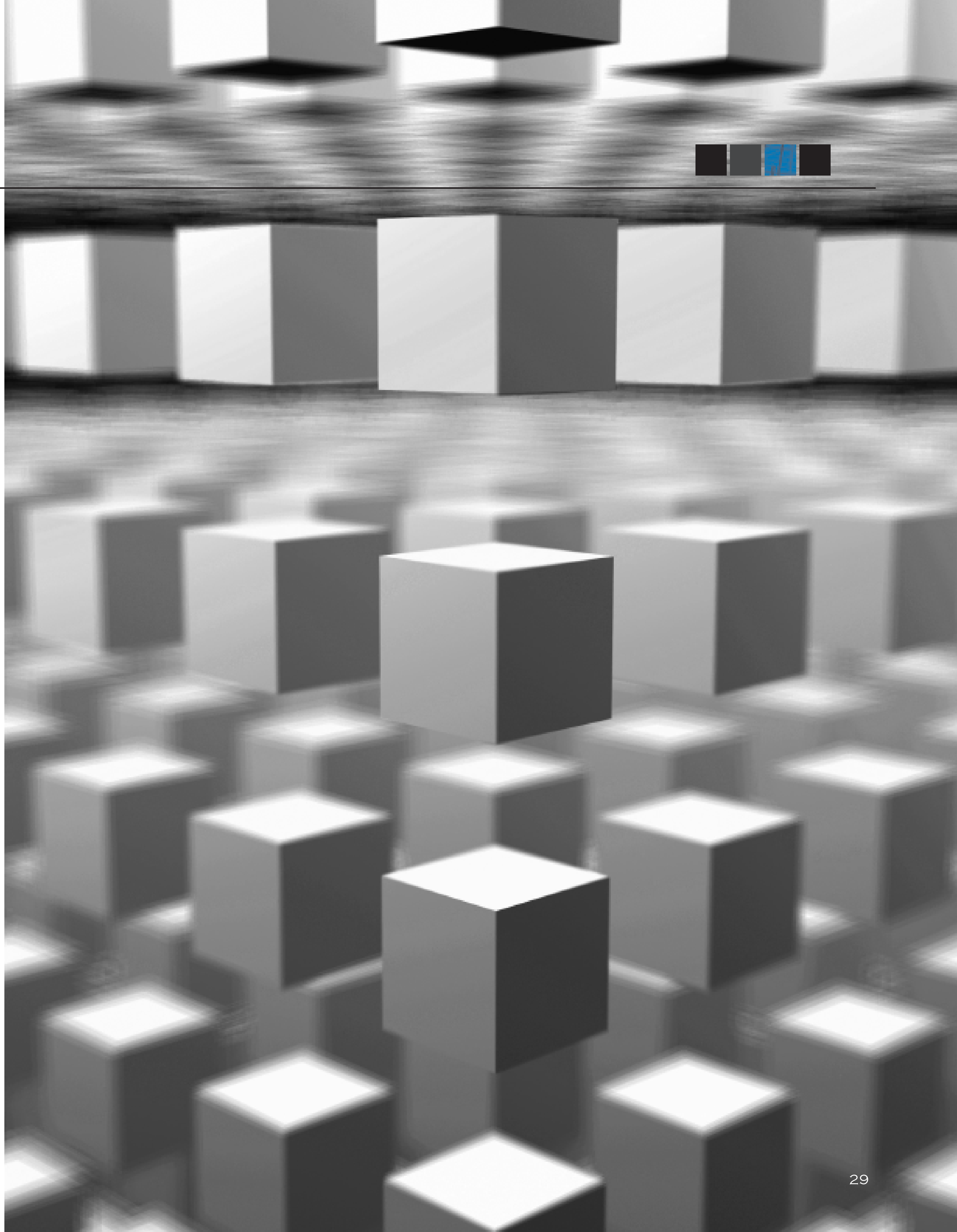
Three-dimensional computer models have substantially reduced the need for multiple prototype iterations due to simple design visualization and the ability to automatically compute physical properties such as mass and volume, as well as the efficiency arising from the creation of one "solid model" design. From these digital models, more focused descriptions, such as cross-sectional views, can be created. A 3-D computer model of an entire product is known as a "digital mock up," "digital prototype," or "virtual prototype."[23]

Other evolving technologies such as free-form fabrication, otherwise known as stereo lithography or rapid prototyping, create physical objects directly from 3D computer models and can be thought of as "three dimensional printers." Most of the technologies work by constructing an object, one cross-sectional layer at a time, by depositing a material, typically plastics, wax, ceramics, or other malleable materials, in order to selectively solidify a liquid and create a product representation.

The testing and refinement stage also includes preparations for production. At some point during the development of a concept, there are often capital purchases, as in the Detail Design Phase when tooling needs long lead times, as well as the mustering of human resources for the production of the final product. Production workers are typically training during this stage. Finally, sales and marketing departments refine and prepare for the product release by designing and producing promotion plans and materials.

PHASE FIVE: PRODUCTION RAMP-UP

The production ramp-up phase is the intended outcome of the previous five stages: the actual manufacture of the developed product and delivery to the customer. Production Ramp-up includes initial production runs for preferred customers, extensive production testing in order to carefully evaluate products and identify any remaining flaws not captured during the previous phase. Finally, there is a product launch and the product then becomes available for distribution. While this section does not provide an in-depth overview of this phase, it is often the one that receives the most attention in the media, through factory tours, and with final products "rolling off the assembly line." However, production ramp-up only constitutes a fraction of the actual product development process.



PRODUCT DEVELOPMENT, SUPPLY CHAIN MANAGEMENT AND INDUSTRIAL ORGANIZATION

Essential to understanding the product development process is an understanding of how companies have structured these and other activities based on their respective organizational outlooks, and how this has changed over time. The stage-gate process is a simple, linear representation, which is useful for explaining basic elements of product development. However, it does not fully capture the highly complex, iterative nature of product development and the daunting task of managing this "network of interactions." Furthermore, managers face a high level of product and technological complexity during the development and integration of the systems and subsystems that comprise the final product.

The primary management challenge to a company's product development process, and indeed operation, is one of coordination and synchronization. While companies have established broad guidelines for product development, the management of these processes continuously evolves and is reflective of the need to access different competencies that lie within as well as outside of the organization. As previously mentioned, many companies conduct product development through multi-disciplinary teams and, due to the complex interdependencies between systems, these teams must interact with many others in order to successfully complete the development process. However, cross-functional teams differ in their composition and orientation, but all are on an organizational spectrum between functional organization and a project- or product-focused organization.

In a functional organization, personnel and resources are divided into areas of specialized training, education, or expertise responsibilities in order to pool and link personnel who perform similar functions. In a manufacturing firm, this may include design, marketing, manufacturing, and R&D. Departments such as manufacturing may be further divided into more detailed functions such as purchasing, supplier development, quality, distribution, and manufacturing technology. With a functional emphasis, the strongest links exist between personnel who perform similar functions.

In a project-focused organization, personnel and resources are pooled based on training, education, or expertise in different functional areas and directed toward the development of a product. Teams are formed across disciplines to encourage speed and innovation, emphasizing links between those who work on the same project. For example, a project-focused organization might include the construction of a new office building. A general contractor would need to pool teams skilled in trades such as masonry, plumbing, flooring, electrical systems, roofing and others, but the primary emphasis of the teams would be the rapid and successful construction of the building.

The reality, however, is that most contemporary organizations are neither purely functional or purely project oriented, but lie somewhere in between. Known as a hybrid model or "matrix organization," this orientation mixes both characteristics of a functional organization with that of a project organization where responsibility is shared between two lines of authority. There are several key considerations when attempting to balance an organization between a functional orientation and project orientation[24]:

- Which functions should be kept centralized to take advantage of scale and scope economies by providing engineering services and components to more than one project?
- Which functions should be dispersed among projects in order to maximize the distinctiveness and innovativeness of the individual projects?
- How much authority over budgets and personnel should a project manager have versus managers of departments with a functional orientation?
- To what extent should companies seek a balance between functional and project management by grouping related projects together and then sharing some technologies as well as functions, at least for clusters of similar projects?

Many companies have migrated to a more project-oriented approach in structuring their operations. In companies using this approach, projects are led by a strong manager who has a great deal of autonomy, complete budget authority, strong management and evaluation interaction with the project staff, and strict accountability for the management and performance of the project. A project-oriented management approach is lauded by experts because of its "ability to create distinctive new designs and then quickly move product concepts through the development process and into manufacturing" while overcoming many of the obstacles that hamper product and service delivery in large bureaucratic organizations.[25]

While all of our respondent companies acknowledged efforts to become more project-focused in their product development process, several individuals spoke about the difficulty of "breaking down the walls" during their respective attempts. Another company was structured by division and, though the product development project orientation for one division seemed to be working well, "the other divisions have their little fiefdoms and there is not much we can do about that."

Interestingly, two of the companies interviewed admitted to not only having a strong project orientation but "going too far," a trend documented in several companies by recent research.[26] Both companies were happy with the results of bringing their products to market more quickly through individual projects. However, they had problems aligning different projects, especially when there was no budget for the company's functional areas. Furthermore, participants talked about the increased cost of not coordinating project activities along functions, such as purchasing:

> We were buying 30 different [components] for 30 different products. We became really good at getting these products from the drawing board to the market, but we had no idea how to take advantage of scale. So, our real challenge is how we coordinate these areas that were once the very functional departments we were trying to break down and get to talk everyone else…so how do you coordinate without adding more layers or reverting back [to the previous structure].

Another respondent described the problems as one of "institutional learning" and "memory":

> We became heavily project oriented but the real challenge for our company is how to capture the "lessons learned" from projects. When you have very strong project managers like we do, all of them want to put their name on their individual project. The problem is that when you have twelve of these strong managers, they compete and there is a lot of 'doing things my way' instead of [the company's] way.

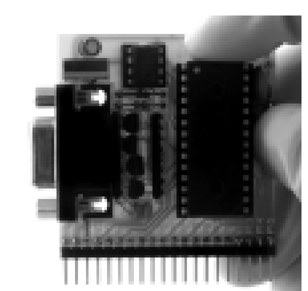
Experts recommend a "multi-project management" approach to deal with the inherent complexity and tradeoffs between functionality and project orientation. Multi-project management is a method for strategically linking products through:

> …product portfolio planning, technologically, through the design of common core components, and organizationally, through overlapping the responsibilities and work of project managers and individual engineers… The firm will develop some totally new products but focus an equal amount of attention on developing common core components and quickly share these across multiple projects.[27]

One respondent company recently restructured their product development process in an effort to take advantage of a strong project orientation but ensure learning across the organization. Like many companies, this company employs product teams that are broken down into systems and subsystems. However, this company chose to "align" its projects with its supply chain/purchasing strategy. Therefore, on each product development team there is representation from purchasing who is charged with aligning product strategies and emphasizing cost reduction through component commonality and reuse, all of which needed to be accounted for early in the planning for the different products. This was especially useful in non-visible components and facilitated a single focus on the individual component's cost, quality, and functionality, as opposed to a multitude of factors based on different design considerations.

A company was having a lot of challenges implementing this organizational structure – "it's tough to re-engineer and align supply chain strategies while in the middle of different product development projects"– but was so far pleased with the cost – savings realized by its efforts.

Discussions of multi-project management and project and functional orientations have primarily focused on the internal operations and structure of manufacturing companies. However, more frequently, manufacturers are relying on companies outside their boundaries especially their suppliers to provide design, components and innovation. The next chapter will explore the origins and evolution of supplier management and how these relationships have evolved as companies have adapted to competitive international markets.



Chapter two: Supply Chain Management

In the last section, we reviewed a "generic" stage-gate process, along with a few examples, in order to better understand the basic elements of product development. In this section, we shift our focus to how, over time, OEMs have delegated an increasing amount of manufacturing responsibility to their suppliers and the different practices used to manage these relationships.

If the stage-gate model is our frame of reference, suppliers are involved in the process in several ways. During Phase Zero, a supply chain strategy in the form of procurement policies, operating procedures, and metrics may be established in order to guide the selection and management of component suppliers. Suppliers might also be engaged during the development of product concepts for their ideas and to see if they might be capable of developing new components that would enhance the performance of future products. Or a supplier may possess an existing technology around which a concept might be further developed.

While product development experts acknowledge the importance of supply chain management practices and its potential impact on product development, supply chain management has traditionally been studied with a more functional "purchasing department" lens. In the stage-gate model, suppliers are first "formally" engaged when a product engineering or purchasing manager drafts the BOM and needs estimates of a purchase price or fabrication costs for each component. Suppliers are again engaged during Phase 3, the Detailed Design Phase, when the specifications are created and "all of the unique parts in the product and the purchase of standard parts from suppliers are identified." Component specifications are then "released" to suppliers for manufacture (see Figure 3 below).

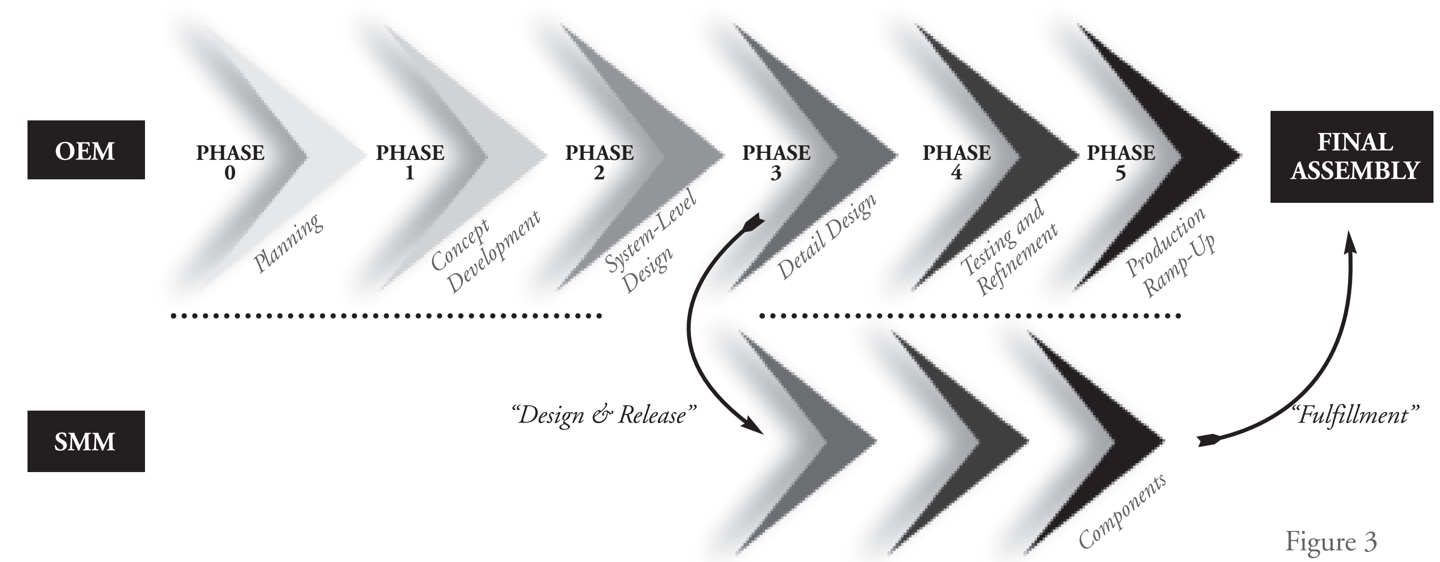


Figure 3

While traditional product development paradigms may view the role of the supplier as reactive to the release of design specifications, supply chain management research and management practices evolved separately. Recent studies recognize the challenges that we have faced: research has, in the past, viewed supply chain management as a related yet separate discipline from product development. This section will introduce the origin and evolution of contemporary supply chain management.

GLOBAL COMPETITION AND THE OUTSOURCING RESPONSE

In the late 1970s and 1980s, U.S. companies faced a competitive crisis: respond to emerging global competition or declare bankruptcy. The perception gradually emerged that the organizational structure of U.S. firms had grown rigid and consequently costly, while firms from other countries such as Germany and Japan were outperforming their American counterparts by focusing on quality and flexibility. Some commentators also attributed Japanese business success to the unique industrial relationships within *Keiretsu*, collaborative networks comprised of banks, large companies, and, in some cases, their suppliers.

Internal corporate practices and foreign competition forced U.S. companies into the "restructuring era," a lengthy sustained campaign to reduce operating costs, primarily focusing on improving operating efficiency and asset divestiture. Individual companies responded by adopting internal business improvement practices such as Total Quality Management (TQM) and Lean/Just-in-Time Manufacturing, or developing their own internal management tools similar to Motorola's development of Six-Sigma. Measures were also taken to move operations out of traditional manufacturing centers such as the Northeast and Great Lakes regions, to low-cost regions in both the United States and abroad to take advantage of less-expensive, non-union labor, as well as lower regulatory and tax burdens.

Second, manufacturers sought to reduce assets – and subsequently corporate overhead – by outsourcing component production and services to other firms. Outsourcing decisions are typically based on a comparison of the "loaded" cost to produce a component and the volume bid of a potential supplier, termed the "make or buy" decision by economists.[28] Outsourcing has been a popular strategy among OEMs because cost savings are realized immediately, often with the effect of boosting a company's stock price when decisions are made and layoffs are announced.[29] Mass layoffs have been devastating to many communities and lives. If there is any silver lining to OEM layoffs it would be the rapid creation and growth of SMMs, accompanied by high rates of job creation to take advantage of these reciprocal outsourcing opportunities.

As cost cutting becomes increasingly important, large firms will outsource more of the operations and therefore buy more and more of their overall products from suppliers. Because of the cost-reduction nature of this outsourcing, most of these decisions are seen as economic transactions from which a firm will benefit. For example, *The Machine That Changed the World* explores changes in the global automobile industry during the 1970s and how U.S. automobile manufacturers thought that cost reductions were best accomplished through an "arms-length," often adversarial approach to continually drive down prices.[30] Many economists applauded transactional outsourcing as an "approach that takes full advantage of market realities" and best accounted for potential opportunism from suppliers seeking to maximize profits at the expense of the OEM.[31]

Ongoing research, supported by our own studies, suggests that the pressure to reduce costs has only increased and that asset reduction, in the words of one respondent, "continues to be a long-term goal of our company and will drive even more outsourcing in the years to come." Furthermore, studies show that not only are companies outsourcing, they are also demanding sharp annual cost reductions from their suppliers over the next five years, ranging between two and five to eight percent a year.[32] Our own interviews find that this trend continues with respondent companies seeking at least a three percent per annum cost reduction from suppliers. A heavy equipment manufacturer shared this:

> We don't make much anymore, but we do a lot of punching holes and putting things together…depending on the product, 60-80 percent of the total cost of our platforms are purchased from suppliers. So we've outsourced a lot of our components and we have wrung a lot of costs out of our company. But that also means that we have to go to our supplier to reduce costs…we really have to lean on them hard.

While the focus of many U.S. OEMs has been outsourcing to cut costs, the focus of this study is to understand how they outsource. The reader will recall that, in the Introduction, we emphasize three "take-home points": investment and outsourcing decisions of large manufacturing firms have huge implications for regional and national economies, these decisions largely reflect the innovativeness of existing and potential suppliers, and these transactions occur in a policy environment that either discourages or cultivates the performance of supplier networks. Our broader point here is that there are many paths to outsourcing and the path that is chosen has consequences far beyond what is reflected in an invoice. For examples of this, we look to the experiences of Japanese automobile manufacturers compared to their U.S. counterparts.

LESSONS FROM JAPANESE FIRMS

Despite the emergence of early business school literature extolling the virtues of outsourcing, as well as the market-rewarded, arms-length practices of OEMs, other studies seek to highlight and understand fundamental differences between how successful, rapidly-growing Japanese firms organize their manufacturing practices compared to their U.S. counterparts, especially in the automobile industry. Much of this research was initially motivated by the realization that, though their successes were not well measured by short-term market indices such as quarterly profits and market capitalization, Japanese automobile manufacturers enjoyed improving quality, reliability, and subsequent growth in market share through most of the 1970s and '80s.

In their retrospective empirical study of automobile manufacturers, studies show that the labor productivity of Japanese automobile firms (as measured by value added per employee) has increased steadily since 1965.[33] The productivity of U.S. firms remained stagnant until the 1980s when these firms began to aggressively adopt Lean/Just-in-Time, TQM, and other management practices first applied by Japanese firms. U.S. automobile manufacturers currently enjoy productivity rates comparable to their Japanese competitors. For example, for at least the past ten years Ford has been a recognized leader in the automobile industry for implementing lean production techniques in its assembly plants.[34]

While U.S. and Japanese firms are on par with regard to labor productivity, the performance and productivity of their respective suppliers is a factor often overlooked. For example, the aforementioned study of the automobile industry also discovered that Japanese suppliers enjoyed steadily increasing productivity once they established a relationship with their OEM customers.[35] However, despite the (late) gains in labor productivity among U.S. OEMs, these improvements did not spill over to their suppliers, offering at least a partial explanation for the recent woes faced by the U.S. automobile industry.[36]

While such studies may be prone to "differences in culture" arguments, recent studies have highlighted similar productivity improvements among American SMMs supplying Japanese OEMs. Due to differences in supplier productivity and its long-term correlation with industry market share, researchers extrapolated that the "secret" to the success of (some) Japanese companies was not simply sophisticated management techniques, but also the way that they managed their supply chain compared to their U.S. counterparts; not "how much" they have outsourced, but rather *how* they outsourced.

TPS, INVENTORY REDUCTION, AND COLLABORATION

Although early studies focused on the Japanese automobile industry at large, no other automobile company has been as widely studied or received as many accolades for its manufacturing practices, steady improvements in quality, and long term growth as the Toyota Motor company. At the heart of Toyota's success has been the Toyota Production System (TPS), the philosophy by which Toyota organizes its manufacturing operations. TPS consists of a number of simple operating practices that emphasize a "long-term philosophy, even at the expense of short-term financial goals."[37]

At the heart of TPS are the concepts "continuous process flow," "leveling," and "pull," emphasizing the continuous utilization of human and capital resources based on the spread of demand over time, but driven by market demand. In the American worldview of "economies of scale" and resulting "batch and queue" production practices, TPS was indeed a new and counter-intuitive concept. The primary goal of TPS is the reduction of waste – or *muda* in Japanese – through a process of continuous improvement known as *Kaizen*. Traditional batch and queue methods result in the buildup of inventory as well as a number of other forms of waste.[38] While much of this waste is produced internally, inventory and its subsequent relationship with time, transportation, and other factors, was seen as the form of waste that necessitated the engagement of suppliers in TPS.

Therefore, TPS posits that in order to manage inventory costs that flow through the supply chain, a very "holistic view" must be taken when working with its suppliers. "Pushing down" inventory to its first tier suppliers may reduce inventory in the OEM but it is only a transfer of waste within the supply chain, eventually resulting in the unnecessary creation of costs to the OEM in the long run. In other words, productivity does not inherently flow from reducing inventory, which can be accomplished at the expense of a supplier, but rather through the optimization of the entire "value chain." Studies using game theory, survey data, and interviews support this all-encompassing strategy showing that benefits and risks of reducing inventory must be shared collaboratively to realize the full benefits of such efficiency initiatives, otherwise resulting in "terminal improvement."[39] As one of our interviewees mentioned:

> The message that we missed in the 1980s from the Japanese was not the power of the Keiretsu or even their mastery of Lean and TQM but rather the deliberate care taken to selectively create collaborative relationships with our suppliers and cultivate those relationships to be as productive as possible…it's this careful, joint problem solving approach that we missed.

TPS = LEAN

The Machine that Changed the World and, later, *Lean Thinking* documented the Toyota Production Systems focusing on manufacturing aspects of the business.

The main tenets of Lean are:

Value: Providing the customer with the right product, for the right price, at the right time.

Value Stream: The set of actions that bring a product from concept to realization, order to delivery, or raw materials to finished goods.

Flow: Seamless movement through value-creating steps.

Pull: Acting only to satisfy customer needs, rather than pushing a product into the marketplace.

Perfection: Continuously improving all of the above elements.

In other words, the success of TPS and its emphasis on waste reduction is not only directly due to the efficiency of a firm's internal operations, but also on collaboratively sharing risk and reward with suppliers. This collaborative approach was well-documented and began to spread among companies.[40] Research attributes the degree to which cost reduction is effective to the scope and intensity of collaboration within the extended enterprise.[41] Specifically, studies show that in the long run, firms that adopt collaboration as a primary mechanism in their cost-reduction activities realize lower total cost of purchased materials.[42]

While Toyota is certainly a success story, it is unlikely that any one company can exactly duplicate the practices of Toyota, nor would they want to. Differences in products, histories, evolution, and operating environments point to the notion that companies must find their own path to profitability and success. Many companies, domestic and foreign, have adopted "lean, collaborative relationships with their supply chain" and moved away from arms-length purchasing relationships as their own version of TPS. Research shows that Chrysler adopted Toyota-like practices that helped restore the company to growth and profitability during the 1990s, including[43]:

- Minimizing the time spent searching for suppliers as well as the time negotiating contracts;
- Minimizing time delays that result from sequential development;
- Improving productivity to give suppliers additional time to search for solutions to design or production problems;
- Supplier investment in dedicated assets, resulting in more timely and efficient communication to speed the flow and accuracy of information between Chrysler and its suppliers.

WHY COLLABORATION?

As the success of companies emphasizing "effective, cooperative, interdependent, and long-term relationships" within their extended enterprises became apparent, researchers set out to understand the root causes of these factors compared to arms-length, market-driven transactions. Different theories emerged but most researchers agreed that information flow, and its subsequent impact on enterprise-wide cost-reduction efforts, seemed to be a critical, differentiating characteristic of collaborative relationships.[44]

Firms engaged in OEM-supplier relationships need to share a great deal of data during their transactions, including quantities, prices, dates, technical specifications, quality attributes, and significant contractual and legal information such as purchase orders, shipment authorizations, receipt acknowledgement, and payment processing.[45] Many basic supply chain problems can be attributed to information asymmetries within the supply chain, typically classified by information flow and quality. For example, research shows that simple inventory positioning problems are attributed to the lack of basic information between members of the supply chain, either from a lack of information or through the transmission of incorrect information.[46] Furthermore, as "bad" information flows through the supply chain it becomes progressively worse, resulting in what has been termed the "bullwhip effect," causing "progressively skewed" inventory levels.[47]

The solution to the "bullwhip effect" is better information flows and interoperability, which can be improved through the use of data management systems.[48] Data quality in terms of accuracy, timeliness, completeness and compatibility is important across users. Other research finds that information accuracy may be relatively more important to buyers while information timeliness may be more important to suppliers.[49] With higher value data, such as technical specifications, sharing and accuracy depends directly on the level of collaboration that exists between companies.[50]

However, no matter how important connectivity, the flow of information is still dependent on collaboration, and studies show that companies must have an open mind regarding collaboration. Furthermore, information in itself is not knowledge, which is of course also dependent on collaboration and will be explored in the next section.

CHALLENGES TO COLLABORATION

Many studies recommend that, in order to share information, firms create a collaborative extended enterprise by adopting collaborative supplier strategies. This is easier said than done as many obstacles to significant change exist. As previously mentioned, purchasing has not often been a strategic focus for many manufacturers.

In many companies, purchasing positions remain "clerical-type, non-value added activity" and rarely receive any form of collaboration training.[51] During our interviews, some respondents described their respective purchasing departments as "dumping grounds for poor performers," "an intellectual wasteland," and "a real armpit in our company."

In many cases, "enlightened" supply chain executives have championed Lean and collaborative supplier relations only to have their efforts reversed by a successor. Or worse, other studies concern themselves with organizations that have embarked upon partnership sourcing without fully understanding the concept, resulting in mistakes that can cost millions.[52] No matter how collaborative a purchasing department may be, collaboration must become a strategic priority embraced at the highest levels of the organization, often necessitating the transformation of internal corporate culture.[53]

This transformation is difficult at best, especially for firms with no history of collaboration. For example, research shows that the more an organization has resisted embracing a collaborative approach, the more difficult it is for the organization to implement it.[54] And even if companies are successful in transforming their culture, surveys show that most OEMs are unlikely to work two tiers down in the supply chain.[55] Business units are not likely to spend their time helping key suppliers get to know and understand the end customer.

U.S. companies who want to institute more collaborative relationships must also overcome a general American political philosophy that has long discouraged collaboration between companies: for most of the twentieth century and even today, companies must contend with a variety of antitrust regulations. The Sherman Act of 1890, the Clayton Act of 1914, the Federal Trade Commission (FTC) Act of 1914, the Hart-Scott-Rodino Act, and other legislation[56] essentially provided for stiff penalties for business-to-business collaboration and have been strictly enforced.

"BI-LATERAL COLLABORATION" IS NOT ENOUGH

Despite these barriers, many U.S. manufacturing firms have instituted effective, collaborative relationships with first-tier suppliers and continue with efforts to align their extended enterprise. While a threshold of collaboration exists to enable lean OEM operations, many firms are adopting a hybrid approach to supply chain collaboration. The result is what Josh Whitford calls "a relational structure that is neither the collaborative production network…nor is it an atomistic world of hostile arm's-length contracting. Rather, it is a complex mix of the two…"[57] In other words, while many firms continue to search for a "one-size-fits-all strategy," they must instead think strategically about how they manage their supply chain and simple classifications may over-simplify the relationship between network-centric manufacturing and innovation.[58]

In the previous chapter, we introduced the notion of modular and integral product architectures.[59] Fine recommends that product architecture not only aid in product development decisions but also impact strategies for designing a firm's supply chain and, in some cases, its entire business model. Dell Computer, for example, uses modular product architecture to execute its cash-forward strategy and manage its inventory levels in the assembly of computers and computer accessories. Dell's modular supply chain management is particularly useful with regard to highly technical components such as microprocessors which, using a strategy called postponement, is one of the last components installed, helping to offset its rapid rate of obsolescence and giving customers access to the latest technology.[60]

Fundamentally, modularization allows for an approach where the physical and performance specifications are conveyed and little attention is paid to what is "inside the box." Many manufacturers have embraced "modularization management" as a way to rapidly catch up with Japanese collaborative practices. Announcements by General Motors, Volkswagen, and others show that these companies are placing big bets on modular supply chain management. For example, in Brazil, Volkswagen's Resende plant is operated by seven first-tier suppliers, each a co-investor and partner in the manufacture of buses and trucks. Each supplier is responsible for assembling their respective module and then integrating it onto the platform.[61] Some researchers argue that this modular approach actually yields better economic performance in the context of globalization since components can be procured globally, based on their performance and cost, then easily plugged-into final platforms.[62]

At a minimum, many OEMs have established cooperative relationships with a few key "mega-suppliers" with whom they have consolidated their purchases.[63] In the automobile industry these suppliers provide entire car "modules," including interiors, power trains, chassis, instrument panels, and others. While establishing close relationships with these suppliers, OEMs focus their resources and competencies on vehicle styling, branding, systems integration, and knowledge management, while the management of most of the supply chain is handled by the partners. However, in light of recent bankruptcies of these strategic partners such as Delphi for GM and Visteon for Ford, many have come to question this strategy.[64]

Products with high component complexity and varying component Clockspeeds are very different than laptops and consumer electronics; early results on full modularization strategies are not encouraging. Volkswagen's aforementioned plant in Brazil has not met the expectations of the company, much less their customers:

> Three years after the opening the plant, the "dream factory" has not met expectations. When the plant opened in mid-1996, VW promised that it would set new standards for productivity. The factory's productivity has turned out to be less than that of comparable American and European plants. VW officials say that this is partly because truck sales have been disappointing, but it is also attributed to inexperienced workers, defective parts, and the flow of parts on the shop floor … a third of the vehicles built at Resende have quality problems.[65]

One of our respondent firms, an aerospace company, had also attempted to implement a modular approach to their supply chains but was unsuccessful "because of the need for visibility in the supply chain." Increased global demand for raw materials such as titanium, aluminum, and specialized steel created vast uncertainties and huge project costs, including backlogs for deliveries, and this often began with suppliers deep in the supply chain:

While our partners are good at keeping us informed, their suppliers may not be good at keeping them informed. We realize that we must all work together and that means not simply assigning our partners jobs and wishing them luck but working with them to manage these challenges. Furthermore, we realized that when we shopped out much our internal manufacturing capacity, we all of the sudden lost massive purchasing power for the remaining raw materials that we need to put the plane together.

Many manufacturers have instituted supplier segmentation strategies based on "strategic importance," or the level at which the supplier is engaged. For example, Reck and Long (1988) find four different supplier involvement classifications common among manufacturers, including: (1) passive; (2) independent; (3) supportive; and (4) integrative. Recent studies show that manufacturing executives prefer integrative strategies but may not have the resources or institutional support for a broad, integrative strategy and must therefore prioritize their supplier management resources accordingly.[66]

All of the firms that participated in our study employed supplier segmentation strategies to manage their respective supply chains. At the integrative level, most companies used a "strategic-partner" classification to denote suppliers whose components "were essential to the performance of our product" and needed to be consulted regularly during the design phase and during product integration. Sole suppliers or suppliers with a proprietary technology – such as automobile airbags – were also classified as strategic because of the difficulty of finding a replacement supplier. At the other end of the spectrum was typically a commodity classification – or what one of our interviewees called a market-based competition – denoting companies whose products were common, possessed little or no differentiating features, were easily procured from another company, and often bought via online auctions. Firms manufacturing washers and screws were an often-cited example of a commodity classification. See Figure 4 below, illustrating John Deere's supplier integration (segmentation) spectrum.

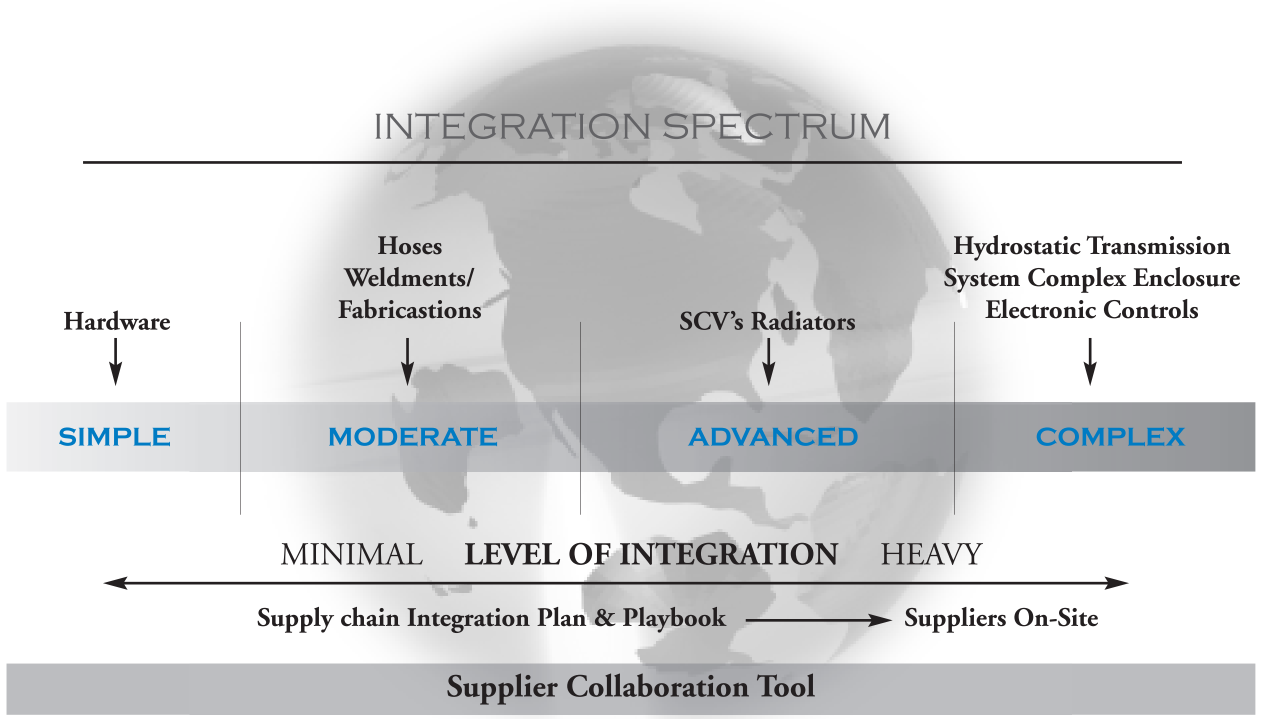


Figure 4

Interestingly, while many U.S. manufacturers, in automobile and other industries, have adopted a more collaborative, if only segmented approach to managing their supply chains, many Japanese manufacturers have adopted a segmented approach to procurement that is similar to their U.S. counterparts.[67] A supply chain manager from a large Japanese automobile manufacturer explained:

> Our company has been known for how we work with our suppliers and that philosophy has been implemented here in the U.S. as well…but we also put a lot of commodities up for e-bid, albeit a small percentage, because we feel confident we can manage that process, make it lean. But when it comes to components we deem critical we either build it or we have people co-located with our suppliers working there every day.

In addition to assigning strategic classifications, manufacturers also rate the performance of their suppliers. While studies show that many firms do not have a formal supplier evaluation process in place[68], all the firms we interviewed rate their suppliers based on performance in the areas of cost, fulfillment, quality, and technology but weight them differently. For example, one company has a very formal process for evaluating suppliers through a standing "supplier performance committee" based on the following distribution:

Quality	30%
Cost	30%
Supply	25%
Technology	15%

One heavy equipment manufacturer classifies its suppliers based on the cost and complexity of their components: Complex, Advanced, Moderate, and Simple. Supplier performance is rated on a scale that goes from Partner, to Key, to Approved, to Conditional based on the component quality, fulfillment, technical support, supplier enthusiasm for solving problems, and cost, relative to that of its competitors.

Many companies use their supply chain ratings to measure the risk of working with that supplier and, therefore, as a "proxy for action." For example, one of the companies we studied rated its suppliers from best to worst using the colors Gold, Silver, Bronze, Yellow, and Red. A supply chain manager from this company shared with us how they use their rating system:

> If we have a commodity supplier that is rated yellow, then we are pretty much looking for another supplier and if they get to red then they are automatically dropped. But we also have strategic partners who are in the red. They are strategic which means we can't do without them so we spend a lot of time working with them … our people are there on a weekly basis making sure that their parts get to us.

Many of the respondents spoke in terms of managing a portfolio of suppliers, some critical, others possessing key technologies; important suppliers who produced good components; and two kinds of commodity suppliers – one where it was merely a purchase and others that really understood Lean and would work with you.

Our broader point is that supply chain departments employ segmentation and rating strategies in an effort to deal with the heterogeneity of their supply base. In the next chapter, we discuss the emerging innovation needs of OEMs and their increasing reliance on suppliers to fulfill these. Yet these "supply chain" and "innovation" perspectives may be in conflict; they do not know in which segment they should place certain suppliers or how to manage them, often to the detriment of the manufacturing network.

SUPPLIER DEVELOPMENT

Two of the biggest questions asked by supply chain managers are: in the world of commodity suppliers and strategic suppliers, how do we make commodity suppliers more innovative and how do we make strategic suppliers perform better? In the latter case, supplier development is a service offered by each of our respondent companies. Supplier development is defined as any effort of a buying firm to increase the performance of a supplier, including assessment and feedback, incentives, competitive pressure, and direct training and investment.[69]

The challenges for suppliers are many and supplier development yields many documented benefits. Supplier development programs are not new and have been around for decades; studies show that this has been one of the distinguishing factors contributing to the overall collaborative strategy and long-term product development and cost-reduction performance of Japanese auto companies such as Toyota and Honda.[70] These companies use their substantial influence to assist small suppliers and build trust.

Increasingly, cost-reduction strategies and willingness to collaborate are no longer enough for OEM suppliers. Many OEMs are reporting the need for supplier improvements in quality, cost, delivery, innovation, and product design; future capabilities of suppliers "may not meet the needs of the buying firm without some type of buying firm intervention."[71]

Some OEMs segment their supplier development offerings strategically as well. For example, one company we interviewed devoted the bulk of its supplier development resources to "drop everything" or short-term fulfillment activities, while it recommended outside consultants or services for suppliers with a good fulfillment track record who may need help to continually improve their internal operations.

Because fulfillment is often dependent on the long-term capabilities as well as the day-to-day management of a supplier's own internal operations, many OEMs have supplier development departments to ensure timely delivery as well as to see if problems are related to more long-term challenges. Furthermore, supplier development may be used to improve the long-term capabilities of firms that have been deemed as strategic (not easily replaced), but may have a low rating.[72]

Companies are ever more concerned with developing new products and more and more are relying on their suppliers to provide solutions to their innovation needs. This may seem counterintuitive given the cost-reduction emphasis of previous supply chain relationships but that is where collaborative relationships stand to benefit these companies.

As products become more complex, OEMs increasingly rely on their suppliers not only for manufacturing, but also design and innovation – and they increasingly comb the world for suppliers with these innovative capabilities.[73]

This section has attempted to summarize the literature and trends as exemplified through that literature, as well as interviews with supply chain personnel, particularly through the lens of a product development process that views purchasing as primarily related to the "design and release" function of that process. Later we will address the question of how the changing innovation needs of OEMs necessitates a different approach to managing their suppliers; no longer as reactive contractors, but rather as strategic innovation partners.

CHAPTER THREE:TECHNOLOGY, PARTNERSHIPS, AND THE EMERGING CONTRIBUTIONS OF SUPPLIERS

The previous chapter discussed various approaches and challenges to OEMs managing and working with their suppliers. During our interviews, OEM purchasing managers demonstrated a good understanding of their respective company's policies and supplier segmentation strategies. Commodity classifications were best understood and most closely related to past purchasing practices; a "market-based competition" classification signifies that the supplier is held to strict price, quality, and fulfillment standards, or else their component "is easily bid out to other suppliers." When it came to working with strategic suppliers, the relationships are "not so easily classified" and "measured differently:" "The way we view, manage, and deal with different strategic suppliers varies substantially." There was an understanding that strategic suppliers provide a component or service to the OEM that is not easily duplicated, and can't simply be "bid out" to another supplier.

While companies must manage their supply chains, they are also faced with the task of developing new technologies as an input into the overall product development process. In the past, these technologies were developed in-house in large corporate laboratories such as Bell Labs and Xerox PARC. However, these labs no longer exist, or exist in very different forms and, with the break-up of regulated monopolies and increasing emphasis on near-market research, companies must increasingly look outside their organization for new ideas and technologies. Enabled by the relaxation of antitrust regulations and spurred by the rapid pace of technological innovation, research partnerships and joint ventures have consequently flourished.

Research joint ventures were first primarily between large OEMs. However, OEMs are also looking to their suppliers, both existing and potential, as an important source of knowledge, not only for the previously discussed reduction of supply chain costs, but also for component and systems innovation. In other words, innovation is becoming the differentiating factor to OEMs in their selection of and deals with suppliers. And though many company executives understand the value of the innovative capabilities of their suppliers, they spoke of how their company struggled with the best way to find, establish, manage, and cultivate these "higher-value-added" relationships.

This chapter will explore how companies pursue technology development, undertake research joint ventures with other companies, and how companies work with their suppliers to manage technology and product development.

THE SEARCH FOR INNOVATION: AN IMPORTANT STEP IN THE PRODUCT DEVELOPMENT PROCESS

In the late 1970s and early 1980s leaders from both industry and government were concerned about the competitiveness of U.S. manufacturing. They were particularly interested in the theories of economists from the so-called Chicago School who posited that regulation was hampering the industrial performance of the nation. Economists were particularly concerned about the impact of antitrust regulation on "dynamic efficiency," arguing that firms were no longer competing only on price but also on quality and innovation.

In knowledge-based industries, a firm's innovative capacity is determined by its access to new technological knowledge and its ability to utilize that knowledge for economic benefit. This is often referred to as the knowledge production function. The knowledge production function assumes firms pursue new economic knowledge as an input into the process of new product development.[74] The greatest source of knowledge creation for knowledge-based industries is research and development[75] and, as research shows, the largest firms undertake the majority of industrial R&D.[76]

Economists saw industry concentration as a natural reaction to the "free-rider" problem inherent in competitive, knowledge-based industries, but also recognized that increasing competition and the move toward deregulation meant that regulated monopolies were no longer a viable option. In 1982, economists Ordover and Willig wrote an article advocating special treatment of research joint ventures (RJVs) – a formal collaborative agreement to jointly conduct research – as an answer to the emerging productive efficiency concerns. They assumed that the effects of market concentration and R&D investment were unknown but realized that dynamic efficiency could only be improved through restraint of antitrust regulation.

> …Significant losses in dynamic efficiency may be caused by the application of antitrust laws, traditionally aimed at preventing harmful concentration of static market power, to R&D-intensive business combinations such as mergers in high-technology sectors or RJVs. [77]

Gradually, the relaxation of antitrust polices gained broad acceptance in the government and, in 1984, Congress enacted the National Cooperative Research Act (NCRA). The NCRA was initially designed to spur joint ventures focused on generic, pre-competitive research by relaxing enforcement of antitrust laws with companies registering under the act and limiting damages that, under previous antitrust rules, were severe.[78]

R&D AND THE SEARCH FOR NEW, INNOVATIVE IDEAS

Discussions of spillovers, Chicago School economics, and antitrust deregulation may be enough to cause the reader's eyes to glaze over but they are important elements in understanding the innovation strategy of firms. As international competition has increased, aggregate levels of industrial R&D have risen sharply. However, now that firms can potentially access new economic knowledge from other sources, including universities and other firms, the focus of their R&D has changed: firms have substantially shifted from a broad portfolio of diverse R&D activities, including fundamental or "basic" research, to those emphasizing "close to the market" development and systems integration.[79]

Many companies create R&D capacity in order to "not necessarily develop technology on our own but understand enough of what is going on in the world to find solutions to our technical problems." In other words, some firms attempt to leverage their internal R&D capabilities with the know-how and product development experiences of their designers and engineers to "absorb, evaluate, and utilize scientific information outside its own boundaries" – what economists Cohen and Levinthal call "absorptive capacity."[80]

Deregulation allowed firms, which had once relied solely on internal R&D, to use their absorptive capacity vis-à-vis formal collaborative relationships to find new and innovative solutions to their product development needs. When NCRA was passed, firms were hesitant to engage in these new research joint ventures.[81] In fact, Congress further relaxed regulations vertically into production joint ventures in 1993 with the passage of the National Cooperative Research and Production Act (NCRPA) and then later created an RJV "safety zone" for firms that comprised less than 20 percent market share.[82] In the 1990s, firms began to pursue more "comprehensive strategies for collaborative R&D."

Many individuals spoke about how their firm had developed mechanisms to "scan" the industrial landscape for new ideas and technologies:

> We have a very stable product that has changed little in the past 15 years. There have been many discussions where we ask 'just what is our next step with regard to our product line.' And while we are quite successful in our core business, we don't really have our hands around IT … we know we have to go out and understand how these technologies can be used to make the lives of our customers easier. There is also a lot going on out there in fuel cells, robotics, nanotech … and we need to find ways to tap into that.

One company had recently restructured its R&D division into a "technology group" which, rather than only conducting in-house R&D, is now primarily responsible for benchmarking technologies from other companies in the industry, labs, universities and suppliers, as well as regulation-mandated environmental and safety technologies.

> I have to understand what our competitors are doing; we are always tearing apart new models. Sometimes this is easy because they are using many of the same components we are, but then there is that 'black box' that takes us some time to figure out. I go to a lot of technology conferences, visit labs … stuff like that. But believe it or not I spend a pretty good chunk of time with our lawyers trying to understand just what is coming down the regulatory pipeline from the EU, the EPA, OSHA … you name it.

Another company structured their R&D department into multi-disciplinary teams responsible for problem solving and technology strategy. For example, the company's "materials team" is a multidisciplinary group comprised of chemists, structural engineers, materials scientists and industry analysts charged with "understanding the direction of our industry, our company's biggest material science challenges, where we stand relative to the industry, then prioritizing and charting out a relevant technology strategy."

All the companies with whom we spoke utilized technology roadmaps to guide their technology search and had articulated technology goals. However, while technologists saw roadmaps as an important strategy to the long-term success of the company, many supply chain managers admitted "we do not get involved in the details of technology road mapping; we usually leave that to the technology group." Furthermore, while many supply chain managers understood the importance of technology and new ideas to their core business, they were not sure exactly what role they could play in this endeavor.

Formal research joint ventures are being undertaken by all seven companies in our study (see figure 5 below). While manufacturing managers were familiar with RJVs, they were typically less familiar than the R&D managers who organized and managed these relationships. With a few exceptions, companies conducted formal RJVs with other large companies. For example, a representative from DaimlerChrysler spoke about her company's recently-announced research partnership with General Motors and BMW to develop new fuel cell technology, along with the their company's overall interest in "blue technology" or ultra-efficient diesel engines: "These projects are so complex that we must partner with other large manufacturers."

RESEARCH JOINT VENTURE

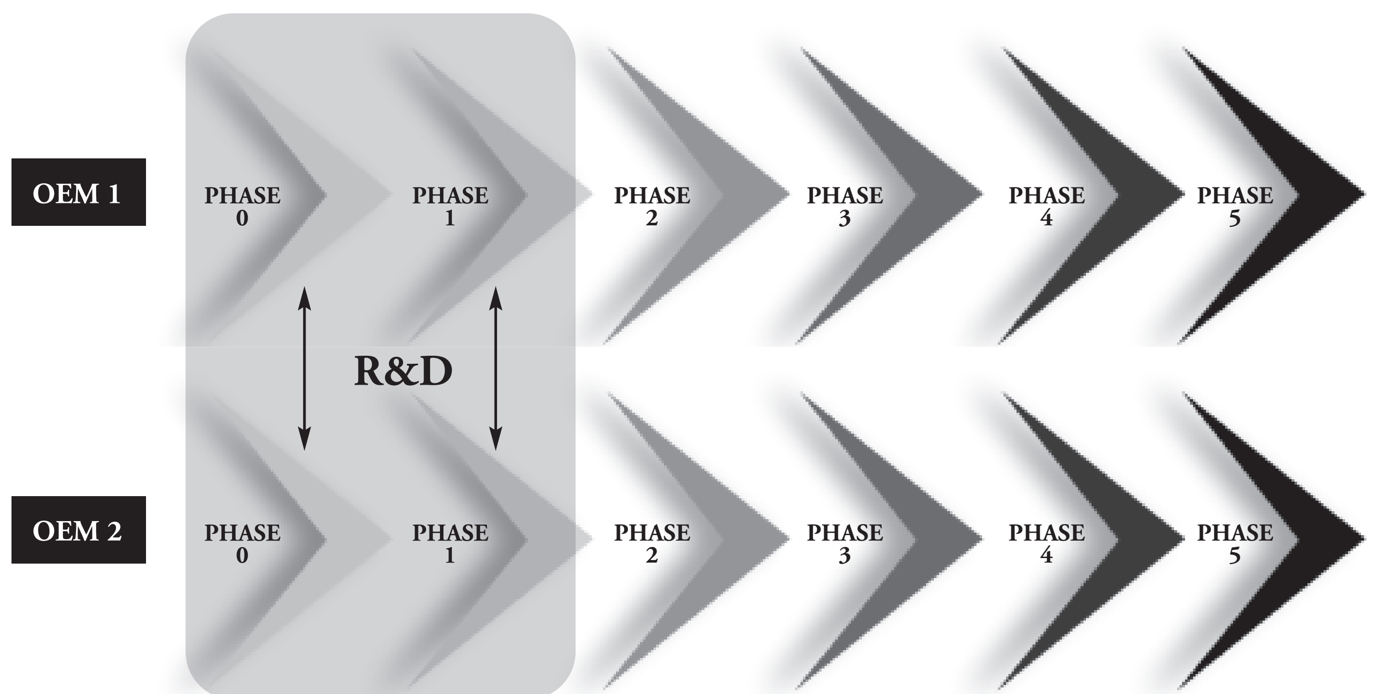


Figure 5

Another example is Toyota's research partnership to develop the Toyota Prius Synergy Drive. Though TPS is well-regarded for its operating efficiency and emphasis on collaborative relationships, Toyota does not have a long history of joint technology or product development with its suppliers. Toyota has long held that technology should only be used if it has been thoroughly tested and serves the needs of the product line, a philosophy that discourages the development and adoption of breakthrough technology. However, Toyota's commitment to developing the "21st-century car" concept, which would later become the Prius, made it necessary to partner with Matsushita Electric in order to develop a new drive train technology through a joint venture called Panasonic EV.[83]

For all seven of the companies that we interviewed, research joint ventures are in the purview of their company's R&D Division. R&D managers are responsible for determining if the development of a desired technology is more efficiently pursued in the context of an RJV and that, at some point prior to the beginning of this relationship, all antitrust and contractual details (including intellectual property) are "worked out between the lawyers." One R&D manager explained:

> We are in a lot of [formal] joint ventures right now … maybe 25 or 30. We have a couple of agreements with universities … but most of them are with large companies because we are really facing a lot of the same technical issues. They have some excellent people who are willing to work with us…whenever we enter into an RJV the IP details are worked out beforehand. That's typically the most time consuming part of the process … but its better we work that out then and get to work rather than spending most of our time in court.

Representatives from Harley-Davidson described how the company's long-term partnership with Porsche to design, develop, and build the engine for the V-Rod motorcycle "really began as a research partnership where we discussed engine technologies very different than anything we have ever built here at Harley." Interviews with personnel from Lockheed Martin Aeronautics spoke about the company's research and manufacturing partnership with Northrop Grumman and BAE Systems, responsible for manufacturing different sections of the Joint Strike Fighter.

While joint ventures may be a valuable conduit to the innovative resources of other companies and possibly result in co-developed technologies, in general, joint ventures require a lot of effort and enjoy very low rates of success.[84] Other research finds that 70 percent of joint ventures have failed to meet partner expectations or have been terminated.[85] Respondent companies in our study supported these findings: "joint ventures are tough…there is a lot of learning about the other company and the personnel and each side really." One company representative lamented "our joint venture with [the partnering company] was really tough and most of us have said that's the last time we do that." However, most firms continue to engage in these partnerships because "these partnerships don't always work well, but at least we learn from the experience…besides we don't want to be left behind."[86]

TECHNOLOGY AND PRODUCT DEVELOPMENT VENTURES WITH SUPPLIERS

As firms look increasingly beyond their organizational borders many are tapping into the innovative capabilities of their supply chain. At first blush, this may seem counterintuitive. After all, studies of industrial organization show that large firms conduct the vast majority of industrial R&D, while small firms typically do not have the resources to undertake formal R&D. What these numbers fail to account for is that SMMs, especially entrepreneurial "start-ups," have the capability to more efficiently bring ideas to market than their larger OEM counterparts and are much more efficient at utilizing R&D from other sources, such as universities and other firms.[87]

SMMs are also a valuable source of innovation because of the knowledge embedded in their own manufacturing processes as well as the relationship with their OEM customer. In the previous chapter, we saw that collaborative relationships enable information flows but as knowledge (initially produced as R&D) in a product category or industry develops, it becomes "cumulative and non-transferable embodied in human, institutional, and facility forms which are immobile and place-specific."[88] This "tacit knowledge" is typically "ill-defined, uncodified, and which they themselves cannot articulate, and which differ from person to person, but which to some extent can be shared by collaborators who have common experience."[89] Therefore, when searching for new, innovative ideas, OEMs must not only use organizational R&D as a proxy for innovation, they must also understand that knowledge exists in a firm's manufacturing processes, the intra-firm relationships themselves, and that long-term collaborative relationships enable the more efficient sharing and transfer of these forms of knowledge.[90]

Tapping into the innovative capabilities of suppliers is well-documented in the microelectronics industry where the rapid pace of technology and subsequent rapid rate of obsolescence of its high-Clockspeed products drives the search for innovation. This search is facilitated by the open, informal networks that exist among highly skilled technical personnel – quite often in different companies – located in areas such as Silicon Valley, Taiwan's Hshsinshu Park, and other high-tech clusters.[91] The microelectronics industry is characterized by a high rate of small-firm spin-offs, often selling components and services back to the original parent company.

For heavy manufacturers of high-component complexity, varying Clockspeed products, there is an even greater need to tap into the innovative capabilities of suppliers because of the inherent challenges of coordinating the disparate operations and responsibilities of an extended enterprise. Studies show that when suppliers are involved in manufacturing new product development, time-to-market is substantially reduced for a variety of products.[92] For example, by working with its suppliers more closely during product development, Chrysler reduced its average development times from 54 months in 1987, to 29 months by 1996, and then down to 23 months by 1998 on the development of the Dodge Durango.[93] Studies also show that other benefits accrue to OEMs that involve suppliers in product development such as reduced cycle time, improved quality, more rapid technological development, and reduced costs.[94] Furthermore, these studies also indicate a relationship between supplier involvement and end-product success.[95]

The technology and supply chain functions of large manufacturing OEMs are typically customers of their company's product development process. However, both have their respective outlooks when it comes to working with suppliers. In general, technology departments manage their (limited) supplier relationships in a manner most conducive to the development of new technologies; supply chain/purchasing departments emphasize cost savings and fulfillment. Due to the immediate visibility of costs and the limited participation of suppliers in technology development, the cost-saving goals of purchasing departments typically win out.

Furthermore, as is made clear by the respondent comments below, involving suppliers in new product development was a new and uncomfortable undertaking for many companies:

> Our suppliers are our greatest untapped resource. We don't know how to effectively and equitably integrate them into our business processes.
>
> Proactive is a not a word I would use to describe our approach to involving our suppliers in product development.
>
> We do not have a good forum for tapping into our suppliers.
>
> We are not sure how to involve our suppliers in product development.
>
> Integration to us does not imply integration into the product development process.
>
> We are often our own worst enemy when it comes to involving suppliers in new product development.

The vast majority of both technology and product development managers, and some supply chain managers, identified "cost-cutting pressures" as a primary obstacle to involving suppliers in the overall product development process. During interviews, we detected frustration from the comments made, for example, by product development personnel about their respective purchasing departments:

> There is always that new guy in purchasing who wants to prove their worth and does it by taking all the slack out of the system. The problem is that removing that slack doesn't show negative results until that guy who made the decision is long down the road.

Another talked about how our purchasing practices are "wrecking our trust with our suppliers" so they often don't share much [with us] anymore:

> I don't think we really understand that if we wring these costs out of suppliers they will choose to not work with us in areas like product development. How will they do that when they don't trust us? I am sure there are a lot of ideas that could be pulled out of them [suppliers] … these suppliers have a lot to offer and we haven't quite gotten the message about collaboration.

Another company purchasing representative spoke about the relationship between levels of trust and "openness" of suppliers specifically during the quoting process:

> Many suppliers don't feel comfortable collaborating unless they have had a chance to quote, and based on that quote, have a purchase order in hand. They have either experienced, or are afraid of having their idea 'stolen' by the OEM and given to a low cost manufacturer that did not come up with the idea by themselves.

BARRIERS TO COLLABORATION

This study has outlined the major stages of a typical product development process, the design and evolution of supply chain management, and various strategies for involving suppliers in cost-reduction, technology development, and the overall product development process. Interviews with R&D, product design, and manufacturing personnel support the fact that OEMs understand the need to be more innovative; integrating suppliers broadly into product development processes is a potential solution, but different perceptions of need and urgency exist. Our study also finds that while arms-length, commodity-based transactions are appropriate for some components, successful technology development, supply chain management, and overall product development are directly dependent on "intensely collaborative" relationships both within an OEM and with suppliers across different stages of the product development process.

BARRIERS TO INVOLVING SUPPLIERS IN PRODUCT DEVELOPMENT*

Supplier capability	62%
Cost-reduction strategies	36%
Internal coordination challenges	34%
Misaligned incentives or strategies	25%
Inadequate training	19%
Changes in personnel	16%
Other	27%

* Based on an open question of the largest barriers to involving suppliers in product development.

Later in this chapter, we discuss Boeing's recent strategy to base sourcing decisions for the 787 frame on the capability of a supplier to manufacture carbon fiber composites. The seven firms chosen as strategic airframe partners are large companies in their own right but the 787 is comprised of thousands of components from companies of all sizes, including many SMMs. What makes their selection different from sourcing on previous Boeing products is the increased emphasis on technological capability; what makes their relationship with the OEM different is the emphasis on integration within the entire 787 product development project.

While Boeing's strategy is the most all-encompassing, all OEMs interviewed recognized the need for increased supplier integration; in so doing all face challenges specific to collaboration. For many OEM respondents, barriers to collaboration are created by the inability of the company to coordinate and align internal resources and policies to encourage supplier integration in product development. In our interviews, 36 percent of respondents cited cost-reduction strategies as a primary barrier to collaboration. These frustrations were especially acute with R&D personnel who were tasked with working with suppliers to develop new technologies but could not "overcome our internal drive to reduce costs." In fact, OEM personnel also cited internal coordination challenges (34 percent) and misaligned incentives or strategies (25 percent) as significant barriers to product development collaboration with suppliers.

Firms attempt to overcome these challenges through different management techniques, especially the restructuring of their internal processes to leverage internal R&D and tacit knowledge, as well as to break down functional barriers. Most OEMs had created multi-disciplinary purchasing teams or technology benchmarking teams in an effort to overcome these coordination challenges. Follow up questions found that employees have not been adequately trained (19 percent) to operate in a highly complex, horizontally integrated and interdependent network that operates most effectively via collaboration, nor have organizations necessarily been structured as such. The impact of poor training or lack of consistency in skill sets is exacerbated by changes in personnel (16 percent). This instability or staff turnover often leads to reversals in decisions and the need to reestablish and rebuild relationships resulting in time delays and lost efficiency.

Additionally, the defense industry faces unique challenges in the area of collaboration that are not experienced by commercial industries. Federal acquisition regulations (FAR) encouraging arms-length relationships to ensure competition and objectivity in some scenarios do not foster the close relationship and trust required for effective collaboration. Restrictions on length of contracts do not allow for long-term relationship security. Changing customers and their political influences affect stability of requirements and focus areas as well as budget decisions.

OEM respondents most often cited supplier capability – 62 percent – as the largest barrier to the collaborative involvement of suppliers in product development. According to OEMs these consist of technical capabilities to "understand, at a minimum, the system to which they would be supplying, not to mention the complete platform." However, OEM representatives also spoke of collaboration skills needed to work with OEM personnel "from the purchasing manager to the scientist." Furthermore, many SMMs "do not have capability to innovate…advance up the value chain." The confluence of these factors, along with internal structural challenges within OEMs, impacts the performance, the competitiveness of the entire manufacturing network.

NACFAM is undertaking a Supply Chain Integration (SCI) initiative to understand the complexities of network-centric manufacturing. Taking a network rather than OEM-centric perspective, including SMMs (the first workshop of the project was titled "Voice of the Small Manufacturer"), the initiative also focuses on specific issues related to the IT capabilities of the entire network as well as the standardization of data protocols and information exchanged within that network. SCI also explores barriers to collaboration within supply chains, and its results support our findings: "the first barrier to collaboration resides in the capabilities of the supply chain." In summary, while OEMs face numerous internal challenges, the operational and technological capabilities of their suppliers present the greatest challenge to the product development network, including OEMs and their suppliers.

Despite these challenges and frustrations, many companies have developed mechanisms that attempt to tap into the innovative capabilities of their suppliers. Some OEMs take what we call a "Reactive Integration" approach, where the supplier is responsible for introducing ideas and innovations to their OEM customer, while OEMs in turn involve technical advisors or personnel as part of the procurement process to understand these new innovations. Other companies, especially in aerospace and defense (and others outside this study), seem to take a more "Proactive Integration" approach and not only involve suppliers early in the product development process, but also go to great lengths to understand the innovative capabilities of their suppliers while concurrently pursuing targeted high-risk partnership investments to develop new technologies to enhance the capabilities and performance of the final product.

REACTIVE INTEGRATION

In five of the seven companies in our study, responsibility for tracking and tapping into the innovative capabilities of suppliers rests with their respective purchasing departments, including multidisciplinary purchasing teams with links into technology departments. By working through purchasing, companies can keep track of existing suppliers and their innovations and status, though this may depend on the company's level of commitment to collaboration. At the center of Reactive Integration is the purchasing manager or multi-disciplinary purchasing team who "spend a lot of time talking to suppliers so they understand where our company is going and what we're going to need."

We term these relationships as "reactive" due to the fact that companies have created mechanisms, usually informal, that allow the supplier to introduce new ideas and innovation to the OEM. In all five companies that were structured in this way, OEMs did have technology partnerships with a few suppliers that were handled by R&D but, while the purchasing personnel were familiar with these partnerships, these were "typically handled by R&D or came up on an ad hoc basis." In fact, during an interview with a purchasing manager, she received a call from a supplier wanting her to "come down today and take a look at a new idea he has been working on for a couple of months." She went on to describe the close relationship that existed with their local suppliers, "We pretty much know what these guys are working on and if we don't they make sure we know…this is my technology partnership."

One purchasing manager said that her teams evaluated a new technology based on whether it was a unique selling proposition (USP) and whether that USP justified additional component cost:

> Suppliers bring us technologies because they are trying to increase sales … we are looking to save money so we first ask ourselves whether or not a customer would like this and, if so, if it's worth our while. Some new ideas are easy to buy into, for others, we may just break even but it may be worth it. Finally, there are a lot of these suggestions that are put to the side because it would be too much effort to get onto our products, it's unproven, or we don't think it's an idea worth paying more for.

When asked about the search for innovation, many of these individuals spoke about the "incremental nature of improvements," for their respective products. "After all," said one respondent, "just how good can a windshield wiper get?" Suppliers are typically rated on technology and engineering but, when asked about how these metrics were reflective of a supplier's capabilities to innovate, one purchasing managers responded:

> They don't … these metrics are primarily focused on the cost and quality of the component. Now if they can employ some kind of new technology that makes the part cheaper, or maybe stronger or lighter, then great. Otherwise, it's pretty tough.

This incremental approach may help reinforce existing relationships with suppliers however, as one responded explained, this also inculcates a general "risk-adverse attitude throughout our company" when it comes to implementing new technologies:

> We first want something that we know will work – it must be proven – then we look at how much value a new technology might add to our final platform; is this something our customers really want? You have to do that because new technologies are expensive … lots of risk there.

Companies often did not have formal mechanisms to partner with their suppliers to develop innovative new components, however, many were trying to figure out how to best keep track of the technical competencies of their suppliers and how this related to the rest of the industry. One company had recently created a "supplier benchmarking team," comprised of members of the technology group who reported to the purchasing manager and who were responsible for "understand[ing] the state of the art and where suppliers in the industry – not just to their company – lie with regard to capability." Another company had, in the past five years, tasked technical personnel to become "corporate experts" whose job is to understand the state of the art in the industry, understand its installation, costs-including manufacturing costs-tolerances, and reliability. These corporate experts are a resource available to both designers and procurement personnel.

OEMs that we consider reactive also described "one-off" strategic relationships that had evolved over time but, though they were considered "strategic," did not conform to their overall supplier management strategy. OEMs shared early design concepts with these suppliers or sometimes approached the supplier with a problem, asking them to come up with a solution. A well-publicized case is the involvement and innovative approach taken by Magna, one of Chrysler's strategic suppliers, to introduce "stow and go" seating. Interestingly, many procurement managers had a difficult time characterizing a ubiquitous management strategy for dealing with strategic partners as opposed to the market-based/commodity relationships:

> We've got a few strategic partners that I'm not sure you can put into a box. They've been with us for a long time … they face the same pressure to reduce costs that the other suppliers do but for whatever reason they are treated a little different and get by with a little more.

When asked why this was the case, the respondent answered:

> Well, they've come up with some great stuff. We trust them to come up with new [components] at a pretty decent price … they sometimes know our problems [with this part of the product] better than we do.

One purchasing representative talked about how "though we have procedures and metrics for evaluating components, [the supplier] had a new idea that they took directly to the executive level. Senior management bought into the idea and we were told 'get this on to the next' [product] and so that is what we did." In summary, though many companies struggle to manage and classify these heterogeneous, often ad hoc, relationships with strategic suppliers, they are "permitted" because of the value and innovation provided therein.

PROACTIVE INTEGRATION

Though less common among the companies in this study, "Proactive Integration" is a technology-driven approach that can be characterized as working in close cooperation with suppliers to develop the technological capability of product components. While many of the respondent companies managed strategic supplier partnerships, the supplier management techniques used by Lockheed Martin's Advanced Development Program (ADP) – otherwise know as "Skunk Works" – seem to best embody the Proactive Integration approach of involving suppliers in the product development process, as well as efforts to fund and cultivate their technological capabilities.

Currently led by Frank Capuccio, ADP is a centralized product development group for Lockheed Martin located in Palmdale, CA. Well known examples of Skunk Works' break-through military technologies include the U-2 spy plane, the SR-71 spy plane, the F-117 Stealth Fighter, and the B-2 Stealth Bomber. What may be less well known is that ADP is also the company's central product development center and that "only thirty percent of ADP is classified as Top Secret."

Skunk Works was created in the early 1940s by an aerospace engineer named Kelly Johnson. Known as a strong-willed project manager, Johnson ran an operation purposely separated from the corporate structure to "push the state of the art" and look 10-15 years down the road to develop next generation aircraft technology for Lockheed Martin. Its relative isolation from the Lockheed Martin corporate hierarchy and its autonomy to be "less profitable in order to create an environment where risk-taking is possible and innovation can flourish" has been at the heart of its success. Furthermore, with "about 350 projects" in the development pipeline, ADP is a high-volume, low-overhead operation that encourages "high-risk, high-payoff development … of cutting edge technologies that the customer eagerly needs or wants to exploit."[96] By keeping project investments and production lots small, and taking more of a portfolio approach to the development of technology, the idea is to trade "upper management" oversight for autonomy as long as success is assured in the long-run.

This "isolated" portfolio approach to product and technology development is especially important given the difficulties of working in the defense industry and the complex nature of the products; lengthy development times not only include design and research, but also the appropriations and procurement process. Lockheed Martin must therefore manage an intensive product development process "limited by the constraints of the government procurement system" with the development of the most advanced technology to best equip the war fighter. For some mass-produced military equipment, traditional methods and incremental innovations seem to "work ok" but the more difficult challenge, according to one ADP representative, is to create "breakthrough, paradigm-changing" innovations. After all, he offers, "why would you want to incrementally improve the U-2 … a paradigm-changing technology requires radical innovation."

While Lockheed Martin maintains a strong internal R&D portfolio, its never-ending push for innovation long ago necessitated "an externally-focused approach to finding or developing a technology, complementing our internal capabilities, to produce the next great platform." This approach was especially important to Lockheed Martin as the company moves in the direction of becoming more of a systems integrator with core competencies in the design, management, and final assembly of complex aerospace platforms. ADP has already begun to take a more proactive approach to working with suppliers, existing and new. For example, "if DOD comes to us and says, we want a functional well-performing missile for $250,000, we immediately know our constraints and there is no way that we can look to our traditional supply base to develop this."

KELLY'S RULES

Late one evening Kelly Johnson wrote out a set of guidelines on a sheet of paper and posted them behind his desk on the shop floor. These guidelines came to be known as "Kelly's Rules" and provided what one Skunk Works official called "our general working philosophy for coming up with some of the most path-breaking aircraft in history – it is really our guide to innovation." These rules were subsequently adopted by Johnson's successor, Ben Rich, and became part of Skunk Works standard operating procedure:

1. **The Skunk Works' program manager must be delegated practically complete control of his program in all aspects. He should report to a division president or higher.**
2. **Strong but small project offices must be provided both by the military and industry.**
3. **The number of people having any connection with the project must be restricted in an almost vicious manner. Use a small number of good people.**
4. **A very simple drawing and drawing release system with great flexibility for making changes must be provided.**
5. **There must be a minimum number of reports required, but important work must be recorded thoroughly.**
6. **There must be a monthly cost review covering not only what has been spent and committed but also costs projected through the conclusion of the program. Don't have the books ninety days late and don't surprise the customer with sudden overruns.**
7. **The contractor must be delegated and must assume more than normal responsibility to get good vendor bids for subcontracting on the project. Commercial bid procedures are very often better than military ones.**
8. **The inspection system as currently used by Skunk Works, which has been approved by both the Air Force and the Navy, meets the intent of existing military requirements and should be used on new projects. Push more basic inspection responsibility back to the subcontractors and vendors. Don't duplicate so much inspection.**
9. **The contractor must be delegated the authority to test his final product in flight. He can and must test it in the initial stages. If he doesn't, he rapidly loses his competency to design other vehicles.**
10. **The specifications applying to the hardware must be agreed to in advance of contracting. The Skunk Works practice of having a specification section stating clearly which important military specification items will not knowingly be complied with, and the reasons why is highly recommended.**
11. **Funding a program must be timely so that the contractor doesn't have to keep running to the bank to support government projects.**
12. **There must be absolute mutual trust between the military organization and the contractor with very close liaison on a day-to-day basis. This cuts down misunderstanding and correspondence to an absolute minimum.**
13. **Access by outsiders to the project and its personnel must be strictly controlled by appropriate security measures.**
14. **Because only a few people will be used in engineering and most other areas, ways must be provided to reward good performance through pay, not simply related to the number of personnel supervised.**

In order to fulfill these innovation requirements, ADP works to integrate suppliers, old and new, in the product development process. First, ADP conducts trade studies that attempt to find commercial off-the-shelf (COTS) solutions to the technical challenges confronting them. They then develop a "statement of objectives" to share with existing suppliers. An ADP official noted that a statement of objectives is often crafted that "cannot be met by any of our suppliers, or Lockheed Martin for that matter. This not only pushes our suppliers' capabilities to the limit, it also helps us all think beyond the 'current state.'" In

these cases, ADP releases their statement of objectives to a broader technical community that include other industries, universities, research labs and others. "We then partner with them depending on their capabilities to develop, build, and bring those technologies to our platforms."

For example, when Lockheed was developing an unmanned aerial vehicle (UAV), it sought to develop it within 12 months. In most aerospace projects, a large aerospace company is the typical supplier of landing gear. Only, in this case, the lead time for the UAV landing gear from this particular company was 18 months. Given the emphasis on time, the ADP team proactively searched for suppliers with the capability to manufacture the landing gear "with some additional assistance in engineering some of the components." A team that included design engineers and process engineers was sent to work with this supplier. Not only did the supplier beat the 12 month production deadline, it did it at one tenth the cost compared to the large aerospace supplier.

Lockheed Martin not only proactively looks for solutions to its technical and manufacturing challenges, it also devotes significant resources to help its suppliers build capacity to manufacture advanced technologies, unique to the defense industry. The two main mechanisms for doing this are Independent Research and Development (IRAD) funds or Contract Research and Development (CRAD) provided by the military services or the Defense Advanced Projects Agency (DARPA) in order to investigate or solve complex technical problems of high interest to the Defense Department. ADP also encourages its supplier partners to apply for government-funded technology assistance grants such as the Small Business Innovation Research (SBIR) program and, when needed, offers technical assistance to help them do so.

While CRAD is initiated by the military services, suppliers can come directly to Lockheed Martin Aeronautics with a proposal for IRAD funds, especially if the money may result in "a significant, game-changing platform enhancement." With especially difficult technical challenges, Lockheed has paid for the development of new technologies with non-traditional suppliers. For example, most research on nanotubes and structures was currently occurring in academia so they had to work with universities. Another example was ADP's work with Foam Matrix, a producer of composite materials used in surfboards, to develop and manufacture new aerospace composites.

While ADP has formed a number of partnerships that are driven by the need to rapidly innovate and drive technology, many challenges exist. The most difficult challenge is getting ideas from the lab to supplier fabrication and then "getting those ideas and subsequently those components on the final platform." While all Lockheed personnel seemed impressed with the technology development projects spearheaded by ADP, several non-ADP personnel talked about the "difficulty of keeping up with ADP… sometimes they get 'too skunky' for the rest of the company."

Lockheed Martin Aeronautics, like many other companies, continues to face challenges during the "handoff" between ADP, manufacturing, and the involvement of its suppliers. They are currently focusing on these challenges through "extreme collaboration" between ADP and other units of the company. For example, purchasing representatives from different Lockheed Martin Aerospace programs, such as the Joint Strike Fighter operations based in Fort Worth, Texas, were represented on ADP teams. That way there is "good flow between the development of a new platform technology and to the actual corporate purchasing process." ADP representatives posited that "yes, we need to push the envelop, but at the heart of innovation are relationships and these are based on openness, understanding, and humility… sometimes we lose sight of the simplicity of these tenets." Another ADP representative explained:

> We work with a lot of advanced technologies – mind-blowing stuff – but in our business the development of new technologies really comes down to collaboration. There are so many roadblocks with what we are attempting to do that collaboration becomes the clear enabler to advancing product development. The company has gotten pretty decent at this but it's a constant battle, especially with some of the things coming down the pike from the government.

The Lockheed Martin officials with whom we met continue to think that Skunk Works is indeed a unique and "very critical" institution. Ben Rich, former director of Skunk Works and the man attributed with bringing a number of paradigm-changing innovations to the military, including the U-2, the stealth fighter and bombers, asks:

> If Lockheed's Skunk Works has been a tremendously successful model, why haven't hundreds of other companies tried to emulate it? The reason, I think, is that most other companies don't really understand the concept or scope and limitations, while many others are loath to grant the freedom and independence from management control that really are necessary ingredients for running a successful Skunk Works enterprise … to buck bureaucratic controls inside or outside the government really takes the capability to break down barriers, courage, and vision. It also takes risk, something CEOs are not known for, and support in order to start a new product line or investment in unproven technologies.

ADP/Skunk Works operates well within the confines of the defense industry but how can lessons learned about a centralized product development group that proactively works with its suppliers to develop new technologies be applied in the case of other, civilian manufacturing companies? Examining emerging criticisms of the stage gate model is instructive.

Criticisms are mounting against "traditional" stage gate processes from two directions. One is from Lean-minded practitioners who view stage gate as a "batch" process, which results in high design-in-process inventories and long production lead times. These challenges are attempting to be overcome by reducing the number of gates in a process and by running more production processes concurrently (see the next section on how Boeing is developing and manufacturing the 787 concurrently).

Though we focus primarily on manufacturers of high complexity, multiple component Clockspeed products, the emergence of open innovation models such as that used by Proctor and Gamble and the development of the Linux (software) operating system also question the efficacy of the stage gate model. In their recent article, Larry Huston and Nabil Sakkab – senior executives at Proctor and Gamble, outline P&G's new model of innovation: Connect and Develop. They are working toward an open development system where P&Gs supply base is unbounded. This "global intelligence network" finds solutions where they emerge across the globe, reducing the need for proprietary corporate research, and brings these ideas into the companies well-organized product ideation and launch processes.[97]

With a proactive integration approach, collaboration is a useful method for discovering and co-developing new technologies to "fill the innovation pipeline."[98] Open innovation models offer new ways to bring concepts and technologies from new sources into the company. However, the real challenge remains for companies to structure their operations using Professor Charles Fine's concept of Three-Dimensional Concurrent Engineering (3DCE), where concepts and capabilities once found are integrated across the product development spectrum of large manufacturers of high complexity, multiple component Clockspeed products, including technology development, design, engineering, and manufacturing.[99]

THE MEANING OF INTEGRATION WITHIN OEMS

In our interviews, R&D, supply chain, and product development personnel all spoke of the need for supplier integration. However, when asked what this meant, they all responded in different ways. For R&D and technology development personnel – like those with whom we spoke from ADP, integration generally meant longer-term, close cooperation on research projects focused on solving a well-defined technical problem. For purchasing and supply chain personnel, integration generally referred to fulfillment issues: "working closely with us to account for variability in component demand" as well as efforts to improve component, and therefore final product quality." The meaning of integration for product development engineers was more all-encompassing: "we need to figure out how to engage our suppliers from start to finish." In other words, while supplier integration has different meanings – and therefore values – to different groups within the same company, these functions often have competing and conflicting goals and incentives that impact the overall ability of the company to fully tap into the innovative capabilities of their suppliers.

Based on research cited in earlier sections, it should not come as a surprise that the efficacy of involving suppliers in the product development process is dependent on the level of collaboration that exists between the OEM and supplier.[100] Furthermore, as multiple competencies such as design, engineering, and R&D are shared between OEMs and suppliers, the success of its communication, including technology transfer[101] and use on final products, is directly dependent on the level of collaboration that exists between organizations.[102] Finally, collaboration increases the likelihood of success for the end product.[103]

Based on this research and our interviews, supplier integration into the product development process may be classified by both its scope – how well the supplier is integrated across multiple functions of a firm; and by its intensity – to what degree are the relationships between OEM and supplier truly collaborative? Therefore, intensely collaborative supplier integration across organizational boundaries seems to offer promise and fully enables OEMs to tap into the innovative capabilities of their suppliers. Even Toyota, which is typically cited as best practice in supply chain relations, does not necessarily fully utilize its suppliers because, though there is careful supervision and control of the product development process, there is very little joint design[104] with its suppliers, though recent research shows that this may be changing.[105] The next section explores how Boeing is attempting to work with its suppliers in an intensely collaborative manner through multiple phases of the product development process for the 787 Dreamliner, including the development of new technologies.

BOEING 787 DREAMLINER: A VERY DIFFERENT APPROACH

In 2007, Boeing will deliver to All Nippon Airways (ANA) the first of many 787 Dreamliners, the first time an Asia-based airline had launched a Boeing aircraft. A "delivery" is constituted by a series of test flights with both Boeing pilots, then with ANA pilots, and a final celebratory event marking the "opening" of the order. The delivery of the 787 and subsequent take off for service based in Japan will be the realization of a revolutionary new approach to designing and building an aircraft, substantially different from previous Boeing, and for that matter, most all heavy manufacturing product development processes: one clearly emphasizing partnering and tapping into the innovative capabilities of its suppliers.

In Chapter One, we explored the evolution of the 7E7 concept: a response to Boeing's rapid loss of market share to Airbus. Once the concept was approved, Boeing quickly launched what would become its most ambitious attempt to change its product development process. Very different than the incremental approaches in the past, refinement of the 7E7 concept continued with special attention paid to the customers' needs, by conducting market research and by holding focus groups with airlines, the flying public, airport staff, creativity experts, physicians, psychologists, and others. The 7E7 concept - which became the 787 Dreamliner - emphasizes several key elements in order to realize cost, performance, and delivery targets, including engine fuel efficiency and emissions, life cycle cost reductions, platform flexibility, operating range, and passenger comfort.

In order to meet the needs identified during this market research phase, Boeing realized that it not only needed a break-through design, it also knew that it needed to revolutionize the entire development of the 787, including its relationship with its suppliers. With the right relationships in place, suppliers could also be business partners, providing needed capital, developing new technologies, and helping to share risk in the development and manufacture of a new airplane.

Technology was especially important to the development of the 787, especially during the selection process for the strategic partners. The foundation of a commercial airliner is the airframe, which in turn became the most important determinant in choosing its strategic airframe partners. Boeing knew that it would have to enlist partners most capable of building an advanced airframe – helping it build a frame that would meet the aforementioned requirements for cost savings, fuel efficiency, and performance.

Unlike supplier relationships of the past, in which suppliers made parts and systems to a Boeing design, the new project demanded a far higher level of involvement and a shared, proactive approach to developing new component and manufacturing technologies. While similar to the proactive integration approach used by Lockheed Martin's ADP, Boeing is attempting to fully integrate partners into the entire product development process, from concept refinement to system-level design, manufacture, and delivery. Therefore, the partner selection process was "one of the most important decisions for the entire project … we knew that these partners would constitute our drive to the future and help us push the envelope with this platform."

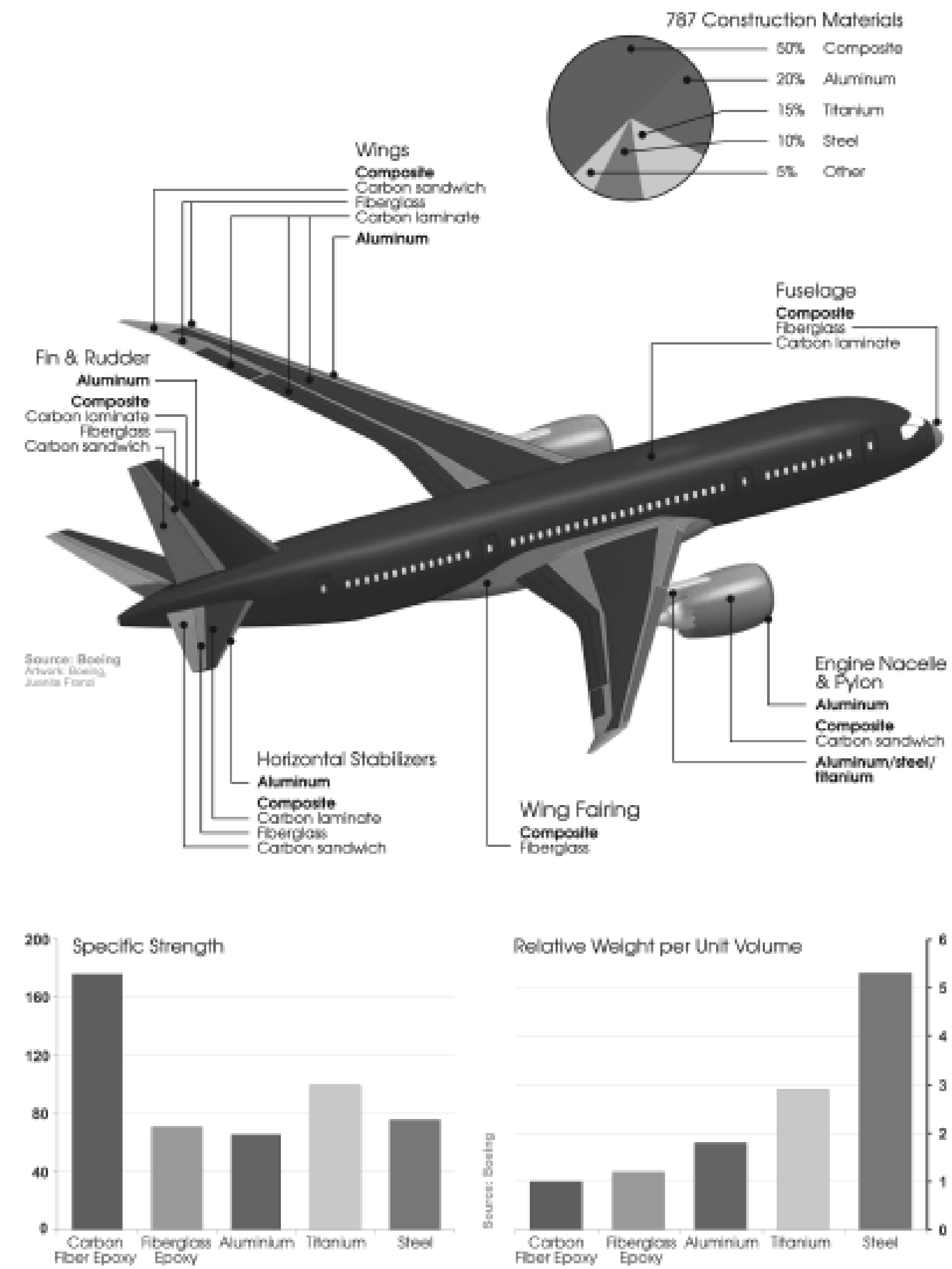
CARBON FIBER COMPOSITES AND THE SELECTION OF STRATEGIC PARTNERS

After consulting experts, funding years of trade studies, and consulting other aerospace companies, Boeing knew that in order to meet these challenges, the 787 frame would need to be built from carbon fiber composites. Carbon fiber composites have been in development since the 1960s and have previously been used in the defense industry. The cost of composites relative to other materials such as aluminum has typically been an obstacle to its wholesale adoption. However, continuing R&D as well as a build up of manufacturing experience with composites and their use in defense applications, has led to a substantial refinement in the materials and commensurate reduction in cost.

Boeing licensed the manufacturing process for these composites from the North Sails Group, a producer of high quality marine sails. Carbon Fiber Reinforced Polymer (CFRP) – a resin that acts as the bonding agent – is combined with strong woven carbon fibers. These carbon fibers act as yarns and are then interlaced, forming a ribbon which is then randomly aligned into a unidirectional tape. The tape is then wrapped around a mold, saturated with polymer to form what is called "prepreg." and then put under pressure with hot gases in an autoclave – "curing" the material. Composites are a light but strong material that is resistant to high temperature and has fewer maintenance requirements because, unlike various metals, it does not corrode or dent easily.[106]

More than 50 percent of the 787 airframe is comprised of carbon fiber composites, allowing for a few distinct advantages in the final product. The material is flexible, yet stronger than aluminum, making it an excellent choice to withstand decades

COMPOSITE MATERIALS



of cabin pressurization and inclement weather. The performance and flexibility of these composites also allow the windows to be significantly enlarged while reducing the overall weight of the aircraft, creating myriad efficiencies such as increased fuel efficiency, longer range, and long-term durability. Due to its composite construction, many of the airframe sections that were once cut, fastened, and bolted together are now "cured" together, reducing by 80 percent the number of fasteners and rivets typically needed (approximately 50,000) on an aircraft model such as 767.

The importance of this composite technology to the 787 airframe is unquestionable and became the foremost criterion for choosing the strategic partners for the manufacture of the airframe. This competitive "technology-based bidding" differed drastically from past practices where Boeing would design most of an aircraft, design and build the tooling, manufacture much of the components, and release the remaining specifications so suppliers could "build to print." With the new program, suppliers are being asked to work in close cooperation with Boeing in order to develop new technologies, create their own designs and specifications, design their own tooling, and manufacture entire sections of the aircraft.[107]

Based on technological capabilities and, in some cases, commitments to develop new product technologies and manufacturing processes, combined with a willingness to share financial and technological risk on the development of the 7E7 concept, Boeing chose the following strategic partners/suppliers:

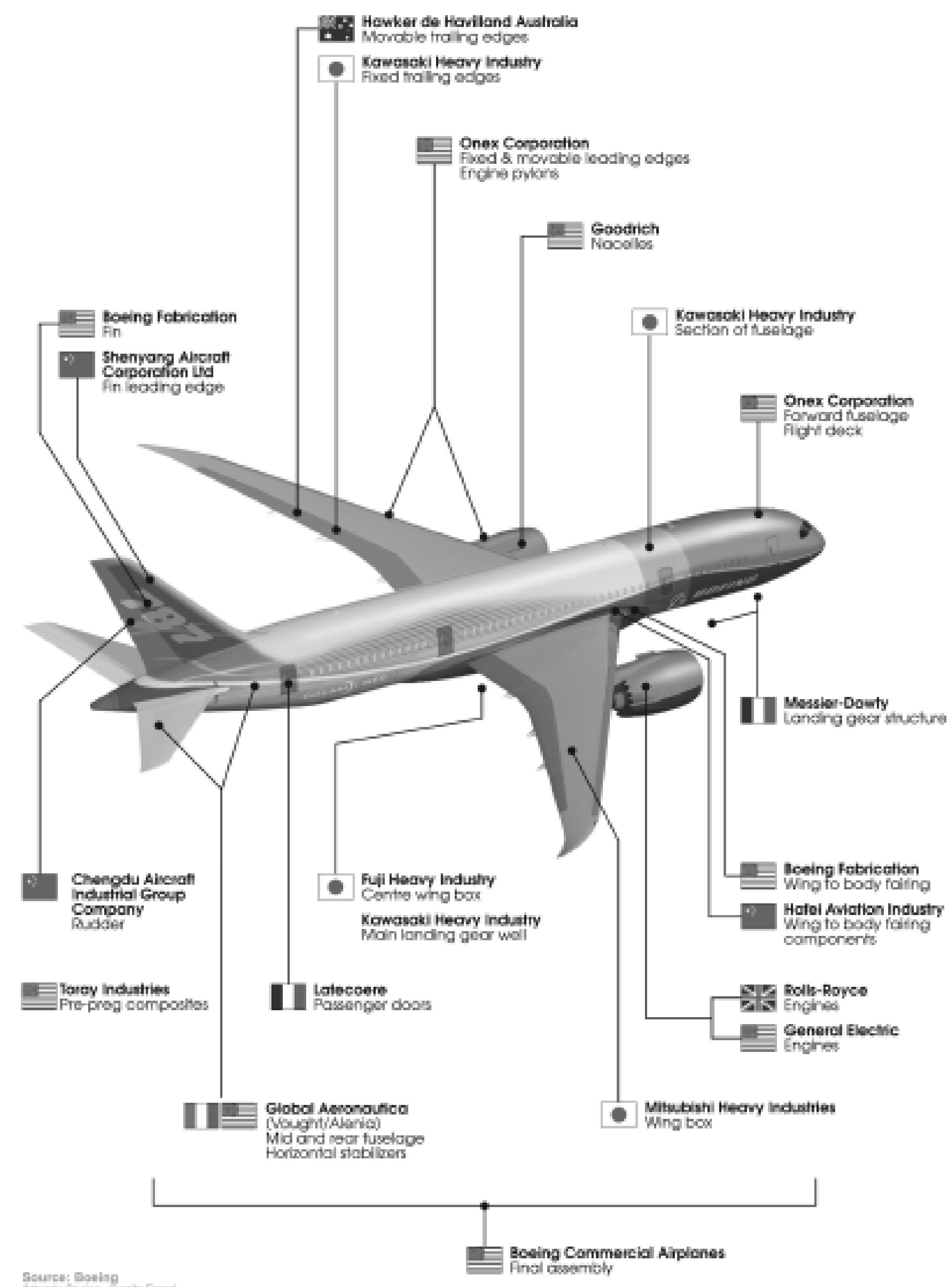
- Alenia of Italy
- Hawker de Havilland of Australia
- Fuji Heavy Industries
- Kawasaki Heavy Industries
- Mitsubishi Heavy Industries
- Vaught Aircraft
- Boeing's Wichita Division, now called Spirit, which was bought by Onex corporation of Canada

Boeing continues to play a key role in the development of the 787, but one that differs substantially from previous models: they created a separate development organization for the 787. And though supplier/partners are manufacturing many key components, such as Fuji's design of the wing, Boeing continues to manufacture 35 percent of its structures for the 787. Boeing's internal R&D is focused on systems integration, materials research and its subsequent manufacturing application, as well as supply chain interoperability and management. Boeing has retained strong cross-functional engineering capabilities in stress, integration and weight – and is not fully cross functional in these areas because of their importance as well as the limited labor pool.[108] As one Boeing engineer described it:

> Though limited, we have purposely retained the engineering and manufacturing know-how to build most of the major structures on the 787… we have to make sure we know, fully understand exactly what our partners are doing. In some cases their lead engineers are former Boeing employees … the most important responsibility we have is managing the complexity of this project

The selection of strategic partners did not end with the airframe but extended to major systems. Long-term technological capability in the context of reducing lifecycle management costs was again the preeminent selection criterion for systems

787 STRUCTURE SUPPLIERS



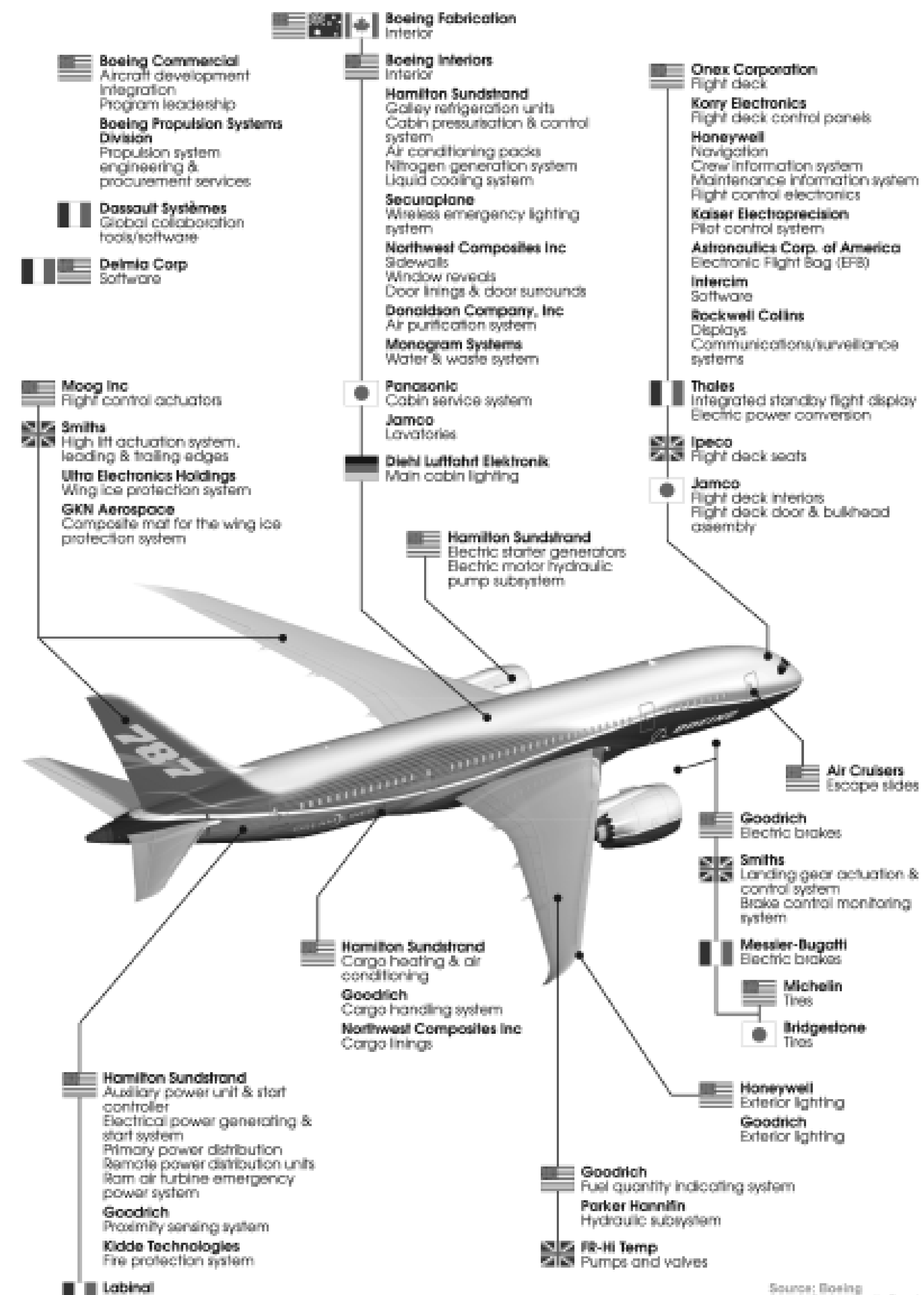
partners. One Boeing representative described this approach as "performance-based modularization," flexible modular systems that purposely expedite technology upgrades, ease of maintenance, or – in the case of the cabin interior – rearrangement based on the needs of the customer. Furthermore, customer service was another important criterion for selection of systems partners; companies like Rolls-Royce, Messier-Dowty, and others offer customer service and maintenance throughout the service life of the aircraft. Based on these criteria, Boeing selected 21 companies from 5 countries for its systems partners. Examples of major systems partners include:

> **Engines:** Rolls-Royce, Pratt and Whitney, and General Electric were in competition for the best two engine choices, driven by performance requirements such as take-off, climb, and cruise performance, as well as fuel consumption, emissions, environmental noise, and installed weight, which added up to greatly reduced fuel consumption per seat (a common performance metric for commercial aircraft): 17 percent better than the 767. The engines were also required to be switched out within 24 hours, which is a huge benefit to both airlines and leasing companies to minimize service delays, allow upgrades, and improve flexibility. Based on these requirements, Rolls-Royce and General Electric were chosen.
>
> **Avionics, Electrical, and Entertainment Systems:** Hamilton Sundstrand and Rockwell Collins were selected based on very advanced radar and electronic systems, as well as their ability to continuously "refresh" the technology throughout the service life of the aircraft. Panasonic was chosen for its capability to offer state-of-the-art entertainment systems that include interactive television, games, and communication devices, interfacing with Boeing's new "Connexion" broadband service, allowing for in-flight, high-speed Internet access.
>
> **Landing Gear:** Messier-Dowty was handed total responsibility for the design, development, testing, and manufacture of the landing gear structure, and immediately began working with Boeing to define the gear and the aircraft interface and integration requirements.

Boeing's product development process for the 787 is called the Airplane Creation Product Strategy (ACPS). While based on a "flowed" stage-gate process, there are important differences for the 787: concurrent product development and planned iterations are emphasized, as opposed to "design and release" or "final design lock" methods. Readers will recall that in a "generic" product development process, suppliers may be consulted during System-level Design (Phase 2) and then fully engaged during Detail Design (Phase 3). In the case of the 787, partners were not only consulted during Concept Development (Phase 1), they were jointly responsible for Systems Level Designs, and subsequently engaged throughout ACPS. This "holistic involvement" is the major difference between 787 ACPS and other limited ways of engaging suppliers in product development.

Within the context of ACPS, the platform is split into hundreds of groups, called "volume teams," based on systems and sub-systems similar to the previous explanation of IPTs. Teams are comprised of Boeing representatives and representatives from relevant strategic partners. However, the mix of personnel may vary substantially, "we have volume teams that are comprised of supplier personnel from all over the world, all working on designing and building a single subsystem." Regardless of their origin, most volume teams include representatives from supply, business support, engineering, manufacturing, and quality. While employees of Boeing play a key role on volume teams, they are often outnumbered by their suppliers – and perhaps suppliers to that supplier – depending on the system:

787 INTERNAL SYSTEMS SUPPLIERS



Source: Boeing

Here in Everett, you see suppliers walking around everywhere. They are co-located here … our people are spread out all over the world working with them … it didn't occur to me just how integrated we all are until a couple of years ago … I walked into one of the first meetings of our [volume] team and realized – hey, I am the only person for Boeing in the room … and the only American. There are plenty of challenges but you can't make a project like this fly without continuous collaboration and 'extreme' connectivity.

With over 10,000 engineering releases and hundreds of volume teams, managing the complexity of this project is an incredible undertaking. Boeing has retained responsibility for cross-platform systems such as plumbing, stress, and thermodynamics because they flow across the various chunks. Boeing's primary role is to manage the cross-functional cooperation between and among in-house staff, suppliers, and – in some cases – the suppliers' suppliers. Previous development projects using the traditional stage-gate process were managed through "hard" mileposts and "on-the-dock" dates. However, the 787 ACPS features eight or nine "systems checks" where development and build progress is evaluated to "ensure there is an understanding of requirements and performance measures, communication between partners, and benchmark progress." Furthermore, there are no firm "on the dock" dates for the suppliers, just firm final delivery dates for the aircraft itself. This created what one Boeing manager called "managing toward delivery."

Supply chain visibility is a critical element to the development of the 787. To meet these visibility needs, Boeing has developed a suite of scheduling tools, performance dynamics, CATIA database systems, and integrated schedules, including a proprietary project management system. When suppliers were selected, they were required to be fully interoperable with Boeing systems, as well as ensure interoperability within their supply chain. Boeing maintains the CATIA "source files" for all system designs and uses ENOVIA, CATIA's product data manager, to ensure design precision and subsequent translation into the master bill of materials.

On previous platforms, Boeing manufactured many of its components in-house and was therefore responsible for the management of its supply chain. When Boeing began the 787 ACPS it intended to cede this responsibility to its strategic partners (using a modular strategy similar to recent efforts in the automobile industry) for the management of their supply chains. However, Boeing personnel quickly realized that full divestiture of supply chain responsibility, especially with the price and supply fluctuations of critical components such as the raw titanium and aluminum materials, was impossible. Boeing learned:

You can never completely cut yourself off from your sub-tiers … at least if you want to build a good product … instead you must ensure you embrace them as part of the extended enterprise and employ your resources wisely so that they too are part of the team…we once thought that our partners could handle that responsibility, but in reality that was like cutting off your arm and expecting it to finish painting your house … besides, with this managing toward delivery schedule you have to always understand what's going on with your suppliers and sub-tier suppliers … visibility is critical.

By working with its suppliers and sub-tier suppliers, Boeing had reduced costs in the overall supply chain by using "blanket purchase orders." Furthermore, because Boeing only needed a fraction of the raw materials it once required, it also saved the company costs for its own internal manufacturing operations. Another Boeing representative summed it up well:

Our ideal state would be to choose our strategic partners based on chunks but have full visibility both in the product configuration and in the supply chain. This would allow us to deploy support resources more quickly.

Many of Boeing's personnel talked about the importance of collaboration to the success of the 787 project. A product engineer shared this:

We have really bought into the Toyota model of collaboration … we even tried to distance ourselves from our sub-tier suppliers but realize that we need to collaborate with our partners so we can collectively make those delivery dates … the success of this project is dependent on this team attitude. What's different is that on previous models we could probably pull off building the thing if we had to … but this is impossible with the 787.

This "intense collaboration" is very important and extends into the assembly of the 787. While Boeing uses three-dimensional modeling is used substantially by Boeing, it also employs full-scale mock ups of the 787 to "represent how the components fit together…it allows us to verify installation, train our technicians, and test for fit and finish … it is a really good way of communicating with our suppliers … we have had a few problems with language but it's a different story when you get people together around one of these mock-ups."

When it comes to the final manufacturing phase of the 787, Boeing wants to substantially reduce the time it takes to assemble each aircraft on the line. Boeing began to experiment with different methods for reducing assembly times for other programs such as the 777 through redesigning and pre-packing module kitting, further "leaning out" their plants and suppliers, as well as migrating the 717, and later the 737 programs to a moving assembly line, similar to the automobile industry (see photo below). The results were tremendous for the 777 which went from an assembly time of 130 days to 71 days in 2001 and into the low twenties by 2005. Boeing aims to assemble the 787 in three days – the fastest of any commercial aircraft.

While it is too early to tell just how successful Boeing's revolutionary new product development process will be, the 787's lighter composite structure; more efficient, more powerful engines; modular, quick-install seating, avionics and entertainment systems, and a number of pleasing features for the flying public have resulted in an impressive array of project benefits. Compared to the 767, a current model with similar dimensions, the 787 will enjoy a 20 percent reduction in weight,[109] 20 percent fuel savings, have 30 percent lower maintenance costs,[110] carry 45 percent more cargo, go faster, fly 2,500 nautical miles further, and offer much greater comfort-all at a 10 percent lower seat-mile cost. Since many hub airports are already "slot constrained," "lesser cities" may now vie for international flights based on the 787's range, efficiency, and ability to land on medium-length runways, opening up at least 400 new city pairs internationally to airlines, including, for example, Nashville to Shanghai.

While some readers may question the applicability of the 787 ACPS approach to supplier management to other manufacturing product development processes, the lesson should be that implementing intensively collaborative supplier relationships that span across organizational boundaries may be the next defining metric of success for manufacturers of high complexity, multiple Clockspeed component products.

NACFAM is a manufacturing think tank committed to improving the competitiveness of U.S. manufacturing. While the primary purpose of this report is to understand how OEMs work with their suppliers to develop new products, it also seeks to understand the relationship of policy, if any, with these trends. During our interviews with company representatives, in addition to questions with regard to supply chain management, innovation, and product development, we also asked questions about the biggest threats to firm and industry competitiveness, as well as about the impact of public policy on competitiveness. Our findings and recommendations are derived specifically from these cases and should therefore be applied cautiously and judiciously to other industries.

IMPLICATIONS FOR PUBLIC POLICY

Our initial points to remember – that large multinational manufacturing firms make large outsourcing decisions with enormous consequences, that at the heart of these decisions is the innovativeness of their supplier partners, existing and potential, and that these transactions occur in an environment that impacts the long-term performance of the manufacturing network – are strongly supported by this study. And because they are supported we must carefully weigh the implications by which public policy and programs can either discourage and inhibit or cultivate and sustain long-term collaboration.

Lawmakers concerned with the competitiveness of domestic manufacturing – networks of OEMs and their suppliers – must recognize that these relationships can be intensely collaborative and that government can play a nurturing role, not only through regulations and incentives but also in the context of public-private partnerships. All too often we are lost in the political-economy rhetoric of free-market principles versus industrial policy, rather than simply acknowledging that government plays a substantial role in our economy. Rather than making zero-sum arguments about whether or not government should be involved, we must shift the focus to *how* government should be involved and the efficacy of that involvement.

When examining the role of policy within the context of supplier capabilities, it is prudent to first take a "return on public investment" outlook in well-established programs designed to assist SMMs. In fact, a wealth of programs exist; in some cases twenty-five to thirty-five different offices represent various agencies and Federal programs already on the books. These programs include Manufacturing Extension Partnership (MEP) offices, Export Assistance Centers, Procurement Technical Assistance Centers, Energy Efficiency Offices, Small Business Technical Centers, Workforce Assistance Centers, and many others. These offices were all set up for the benefit of SMMs, yet their intended beneficiaries do not have the time or resources to visit each of these offices, attempt to understand if they are eligible for service and, if so, how they apply.

Second, the focus of these programs is usually on basic services that do not account for the heterogeneity and innovation needs of SMMs as articulated by their OEM customers. Some firms may need basic business planning and operations assistance, while others may be well-established, Lean, and competitive, but still require access to new technologies and ideas.

These services would be best if tailored to meet the needs of the client: the SMM. Recent efforts by the Iowa MEP center, based at Iowa State University, are pertinent to this discussion. Iowa MEP has divided the state into service regions, each assigned a field agent to interact and with SMMs in their respective region. The field agents are familiar with all the service offerings provided by the state and federal government in Iowa and, in some cases, outside of Iowa. In addition to connecting clients to existing services, field agents also work with faculty from Iowa State and other universities and community colleges to help SMMs solve technical problems.

A broad approach must be taken to identify what resources are available to SMMs and the network at large. The intent of NACFAM's SCI initiative is to develop what we call "a total solution package" – where each stakeholder is identified together with their value proposition – in order to "overcome constraints, and spur diverse public and private stakeholders to collectively enable a multi-tiered network-centric manufacturing capability." An examination of how to reorganize and deliver these existing SMM services may seem like a simple first step, but once these services are catalogued and leveraged, attention can then turn to the unique technology and innovation needs of SMMs.

> **Recommendation:** States and local communities need to create a task force comprised of leaders from both the public and private sector to understand and document existing state and federal programs designed to benefit manufacturers, especially SMMs. The purpose of this task force is to understand how these services might be "packaged" and more effectively deployed for the benefit of eligible SMMs.

It is essential that OEMs – the SMM customer – be engaged in any efforts to create, modify, or combine SMM services. All too often SMM technical assistance is deployed without customer input, as one supplier development manager shared with us:

> [A training service provider] has no clue what we are asking of our supplier. They have the resources but are not set up receive input from us [the OEM] … it's pretty much the equivalent of training someone to work with Intel on a 286 with DOS.

If OEMs understand that these services can benefit their suppliers, they will be more inclined to participate in their deployment. For example, one OEM respondent praised programs located in the state of Ohio, particularly Techsolve, a collaborative, non-profit technical assistance center funded collectively by the Ohio Edison Center Program, NIST MEP, and fees charged for their services. Techsolve is a center of excellence for machine tool technology, one of several centers in Ohio, providing "a unique combination of service offerings from Lean and basic manufacturing management practices to a new program to improve innovation and product development within small companies." The OEM executive had funded several supplier development projects with Techsolve and was very happy with the results:

> If I could, I would move all of my suppliers to Ohio. They really get it and understand what it takes to keep our guys [suppliers] strong and successful.

Earlier we discussed the "public goods" nature of supplier development, especially with suppliers with multiple customers. One respondent spoke of his company's attempt to overcome "costly coordination inefficiencies" through a supplier development consortium with two other OEMs, administered by the Wisconsin MEP. The object of the consortium is to improve the performance of suppliers by first establishing agreement on performance metrics – in this case Manufacturing Critical-path Time (MCT) – then pooling resources through the WMEP to provide technical assistance to common suppliers and others at the discretion of the consortium. The governor of Wisconsin recently announced additional support for the initiative to offset initial evaluation and service delivery costs for any supplier located in Wisconsin as well as to enlist the participation of other OEMs.

While the WMEP initiative is well publicized in Wisconsin, many OEMs are not familiar with public programs designed to assist SMMs. For example, 42 percent of respondents interviewed during our study had never heard of MEP, or know of a public or public-private organization that could aid their suppliers. When asked, interviewees familiar with these programs commented:

> It's tough to get a lot of our executives interested in these programs … it's tough for them to see how it benefits our bottom line … but then again you might say that about supplier relations or supplier development in general. A lot of people have yet to make the connection between the health of our suppliers and our capacity to manufacture here in the United States.

OEMs that were involved with an MEP center or other centers were pleased with their results, though they warned "it takes a lot of time to work with these centers, and they need some guidance … but they know what they are doing and once we trusted them the relationship was very productive."

> **Recommendation:** OEMs are the customers for SMM products and must be engaged in the creation or improvement of existing development or assistance programs for SMMs.

> **Recommendation:** OEMs should take an active role in these programs and have a detailed understanding of how they may improve or impact the performance of their suppliers.

Manufacturing supply chains operate across state and national (and indeed international) boundaries. From the standpoint of our OEM respondents, this was one of the primary weaknesses of the MEP system:

> Many of the states are able to act, for the most part, as 'independent fiefdoms.' Independence can be good relative to understanding local needs, but sometimes it just introduces another layer of 'not invented here,' which gets in the way of propagating best practices across the system.

One OEM involved in the WMEP consortium is attempting to overcome this challenge by deploying the consortium model to other regions in the U.S. where it has suppliers. In the first step, WMEP staff is training personnel from other MEP centers in a location corresponding to a major manufacturing center outside of Wisconsin. Other companies are following suit by working with technical service providers throughout the country.

The network-centric nature of manufacturing supply chains necessitates a national networked infrastructure, which facilitates the combination of services currently funded and available in a format easily accessible to SMMs. Furthermore, in the delivery of these services, OEMs must not only be familiar with these programs, they must fully engage – and be engaged – in an advisory capacity with regard to the content, delivery, and assessment of these services. Finally, these services must be deployed nationally, across state borders, reflecting the national scale of OEM supply chains. The consideration of scale and other concerns (to be discussed later) necessitates the creation of a stable, robust supply chain infrastructure that supports the coordination and nationwide delivery of these services.

THE NEED FOR A U.S. INNOVATION INFRASTRUCTURE

While many of the examples above focus on MEP, this is not an advocacy piece for a particular program or agency. However, the point stands that the United States requires an industrial infrastructure that supports and cultivates the innovation capabilities of SMMs. In fact, for a multitude of reasons MEP has not played a substantial role in the diffusion and adoption of new technologies, new product development, or overall supply chain integration where the performance of the overall manufacturing network is considered. However, with a "U.S. Innovation Infrastructure," technical assistance personnel would work with labs, universities, state technology development organizations, and indeed OEMs, to assist SMMs in their "rapid competitive transformation" – what one OEM respondent called "help[ing] to move suppliers up the value chain."

> There is only so far that Lean can take you. Just because you are Lean does not mean that you are innovative…it's interesting because the skills needed to make someone efficient and organized do not necessarily promote great new ideas and different ways of doing business … a lot of our suppliers get Lean but they have no idea how to come up with the next great idea … product … much less create a system that encourages this kind of thinking and keeps them Lean.

OEM personnel from all industries spoke about the need for innovation and agreed that this would increasingly drive sourcing decisions. However, the degree of need for technology was relative to the company and the complexity of the product. Some respondents spoke of the immediate need – such as that illustrated with Boeing's 787 Dreamliner project – while others said that suppliers would "really need to deal with it a few years down the road." One supply chain executive commented that "a lot of our suppliers are not prepared for this but they are trying hard to be creative, innovative."

Small suppliers often lack the capacity to understand which new technologies and processes are relevant to their business. Many SMMs rely on their OEM customers to help them understand innovation needs but – in the minds of many SMMs – this is perilous given the adversarial cost-reduction strategies undertaken by OEMs. Neither do SMMs have the resources, the technical personnel and expertise, and therefore the capacity to evaluate new productivity-enhancing technologies or ways to create innovative new products.

The United States is fortunate to possess many publicly supported innovation resources such as universities, federal and state laboratories, and a growing number of public-private partnerships dedicated to research and innovation. However, one of the difficulties with public research and other, commercially developed technologies is its recognition, deployment, and adoption by SMMs. Previous efforts to improve technology diffusion and adoption have been primarily based on "push" methods where technology transfer offices attempt to find suitable candidates for their organization's technology. However, the most successful technology diffusion efforts create linkages between the technology needs of a company and development efforts within labs, universities, and commercial technology providers.

Studies show cross-functional teams comprised of individuals with diverse but highly technical backgrounds are effective in identifying and validating the cost effectiveness of technologies that might be used in various industrial applications. However, these teams do not present an effective mechanism to diffuse these innovations to meet the needs of SMMs.

> Once an application of a new technology has been tested and its cost effectiveness has been verified, communicating with companies regarding the potential for applying the technology within their operations can be accomplished by trained, individual field specialists.[111]

Furthermore, it is imperative that the OEM customer be involved in the selection of the technology, especially if "it constitutes a substantial shift in the manufacturing process and impacts the final product or platform."

These technologies can be obtained from a number of sources including national labs, universities, SBIR companies, even from OEM customers themselves. From this "library" of identified technologies, field specialists working with SMMs could best work with experts to find solutions to the particular needs and objectives of the SMM in the context of overall process-oriented technical assistance. Technology diffusion and adoption pilot projects such as the Army's *Miltech* and *Techlink* programs have yielded promising results and point to the potential of such efforts. A dedicated national infrastructure would give programs responsible for the development of high-risk technologies, such as DARPA and the Advanced Technology Program, a venue to both search for radical new ideas as well as disseminate new technologies to SMMs. Significant focused R&D efforts, such as President Bush's Executive Order mandating that a percentage of the SBIR program be devoted to the development of manufacturing, could be better coordinated, along with new initiatives suggested by recent competitiveness reports[112], including:

- A substantial increase in basic research through NSF, the Department of Defense, and others
- A three percent tax for "Innovation Acceleration" grants that invest in novel, high-risk and exploratory research
- Revitalize multidisciplinary research

A national SMM innovation infrastructure would also give mission agencies a valuable conduit to SMMs for the dissemination of information and technologies relevant to their mandate. For example, the Environmental Protection Agency is interested in the development of technologies that help reduce pollutants emitted into the environment, just as the Department of Energy is interested in the development and dissemination of technologies that help companies reduce energy consumption. Pilot programs such as the EPA's Green Suppliers Network demonstrate the effectiveness of meeting mission agency objectives under the premise of cost-reducing technical assistance. The alignment of public goals such as the elimination of pollutants and the reduction of energy use are effectively undertaken in the context of waste reduction, analogous to TPS/Lean, offering public officials, SMMs, and their OEM customers a true win-win situation.

While this report does not focus on the overall impact of regulations on the cost of doing business, we briefly review the capability of a manufacturing network (specifically SMMs) to keep up with the deluge of regulations that not only stem from U.S. agencies, but also from countries to which their OEM customers – or to which the SMMs themselves – export. Personnel from all seven of the OEMs participating in our study cited the emerging environmental regulations, including total lifecycle management or cradle-to-grave requirements (which will reportedly be reflected in ISO 26,000), emanating from the European Union and other areas of the world. Studies show that, for SMMs, compliance with health and safety regulations is especially costly and onerous. More importantly, how will SMMs work with OEMs to understand the impact of these regulations on the final products as well as reengineer the way they do business so that their components are in compliance? A robust innovation infrastructure may hold the answer.

A national infrastructure would not only provide nation-wide coordination of technical services, mission agency requirements, and technology transfer, it would also recognize the distinct needs and capabilities of regional economies. Techsolve's focus on the machine tool industry and Iowa MEP's focus on precision metal fabrication are two examples. Locally-tailored services also allow the combination of services to meet the needs of different industries. For example, WMEP has not only provided Lean services to manufacturers, it has also provided technical assistance to dairy farmers and service industries, allowing for cross-sector organizational learning that may benefit manufacturers who, for example, wish to market directly to customers.

For the few company representatives who were familiar with public programs available to assist SMMs, OEMs most often cited MEP: "MEP is the closest thing we have to an infrastructure to which we can refer our suppliers." However, many OEMs were hesitant to work with public programs because of their "uncertain situation." One OEM supply chain manager described his company's relationship with MEP as analogous to an earlier discussion regarding supplier relations:

> It's the same kind of thing … how can we work with the MEPs and ATPs of the world if we are not even sure if they will be around next year … I am not going to refer one of my suppliers only to have egg on my face because someone pulled the plug on the program.

In other words, relationships established between OEMs, SMMs, and public programs face the same uncertainties as customer-supplier relations in industry: effective coordination and innovation are dependent on stable, intense collaboration. Interestingly, several OEM managers spoke of MEP as a "useful buffer" between the OEM and SMM:

> Sometimes we don't always have our act together with these guys [suppliers]… we send our SD [supplier development] group in and they're wondering, what are these guys doing? Will they put us through a Lean event and then send us a letter demanding an immediate price reduction?…these MEP guys can go in and they are not from [the company] … MEP tries to do what's best for them but we end up benefiting too … they trust the MEP guys, they listen to them, and in the end we benefit too.

A neutral third party can provide stability and help offset many of the challenges to collaboration between OEMs and their suppliers, assuming it enjoys a certain level of institutional stability.

> **Recommendation:** The efficacy and long-term success of these third-party initiatives is dependent on the creation of long-term relationships between OEMs and SMMs, as well as the third-party's operational funding. However, this funding, while stable, must also depend on the satisfaction of its SMM clients and OEM stakeholders.

This report purposely does not discuss funding levels for specific programs or agencies. However, these existing, disparate SMM resources are not of the size and scope that allow for effective national coordination. A national innovation infrastructure is not likely to succeed if it faces instability caused by year-to-year political squabbling, similar to those faced by existing SMM assistance programs (other than SBIR). Consequently, many of these programs are not only beset with quality and performance challenges, the uncertainty of their existence has frustrated and deterred the participation of many OEMs (including our respondents), which results in even greater funding uncertainty.

Industrial partnerships do not conform to the Congressional budget calendar and any successful infrastructure program must recognize this reality. Creative funding mechanisms must be adopted to insulate a national innovation infrastructure from year-to-year political battles, to better serve the needs of SMMs. One idea is to fund such a program through the adoption of a small funding "tax" of agency SMM outreach budgets and – for technology transfer – R&D budgets, similar to the Small Business Innovation Research (SBIR) Program.

> **Recommendation:** A Congressionally-mandated percentage of agency SMM outreach budgets should be set aside to create a robust supply chain infrastructure reflecting the previously articulated recommendations.

Only with a robust nation wide innovation supply chain infrastructure can U.S. manufacturing networks more rapidly adjust to the increasing enterprise-wide need for innovative new components and technologies in the context of the overall product development process, and therefore remain competitive in the international marketplace.

CONCLUSION

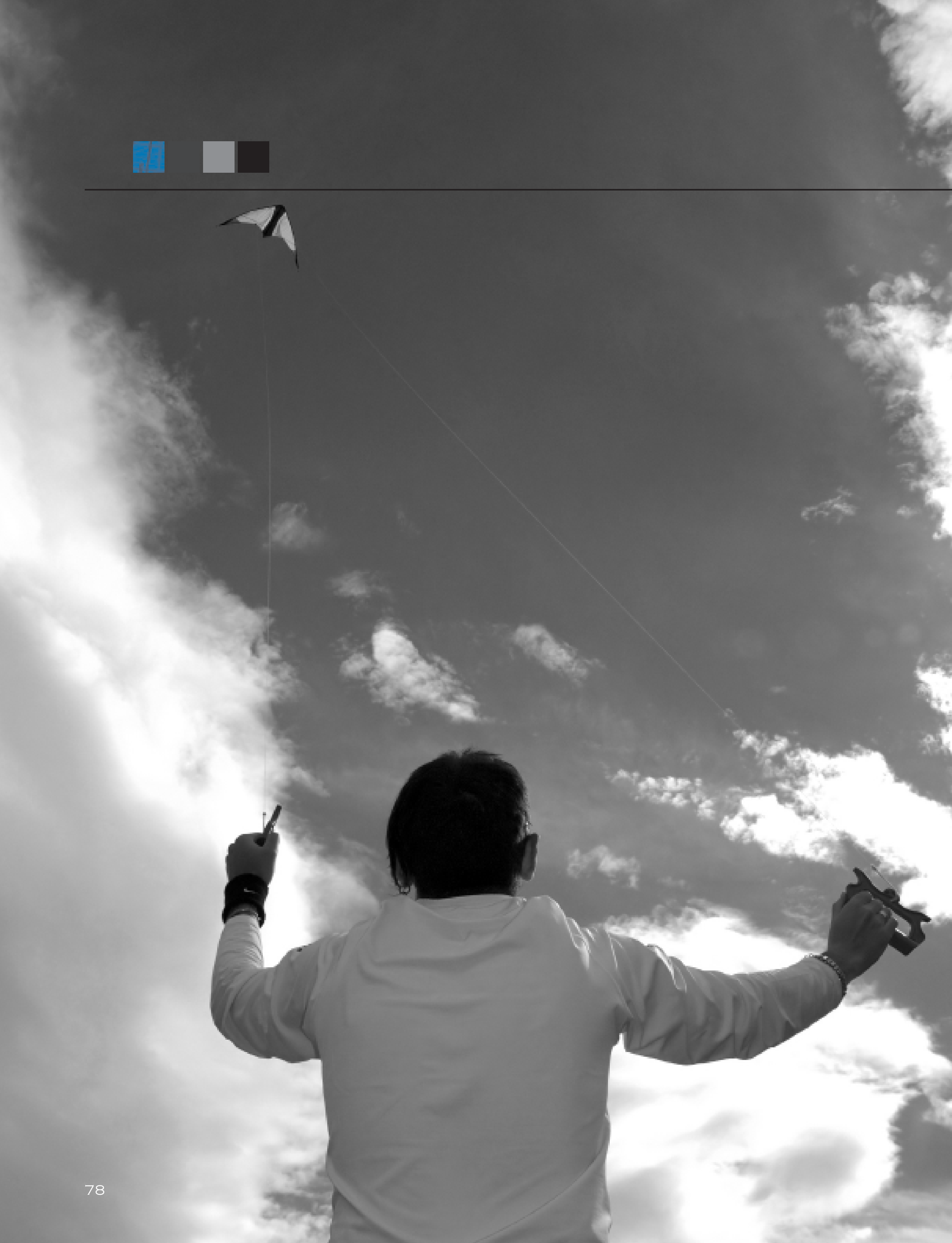
This Chapter briefly recapped the findings of our study, explored their relevance to the competitiveness of U.S. manufacturing, and discussed implications for public policy centered on the development of capabilities and function of manufacturing networks. In the report's Introduction, we state three important points that bear repeating, including:

- The investment and outsourcing decisions of large multinational manufacturing companies have tremendous consequences for the strength and vitality of both regional and national economies.
- At the heart of sourcing are the efficiency, viability, and – most importantly – the innovativeness of suppliers, both existing and potential.
- OEM-supplier transactions occur in a policy environment that can either discourage and inhibit or cultivate and sustain the long-term performance of the overall manufacturing network.

We, of course, leave many stones unturned, keeping our focus on realistic ways to maximize return on investment starting with programs and services that are currently written into law. A logical next-step in leveraging these public resources is to tailor them with the client – the SMM – in mind, with substantial input from their OEM customer. Such efforts should be coordinated nationally but implemented locally with a robust infrastructure, reflecting the full scope of domestic supply chains. Finally, the primary focus of such a national infrastructure must be the building of innovation capacity within network-centric manufacturing.

Building innovation capacity must not focus only on leveraging existing programs and services; it must also include tapping into our country's unrivaled pool of public R&D. Ideally these efforts would be a part of a broader discussion on maximizing return on public R&D investments. We often refer to Donald Stokes' book, *Pasteur's Quadrant*, which explores the evolution of publicly funded research in the U.S.[113] While no one disputes the importance of R&D in society, the danger of the past classification of research into basic – R&D only intended for the pursuit of knowledge; and commercial – research that is close to market – is that we inhibit its use in more practical ways to solve general societal problems. Stokes recommends a purpose-driven approach, one that seeks to expand the boundaries of knowledge with the perspective of seeking solutions for the problems faced by societies. Applied to the challenges of product development and SMM capacity, can we not seek to fulfill the missions of relevant public agencies, especially those that seek to govern the practices of private enterprise, in a way that best supports the competitiveness of manufacturing networks?

The challenges to American manufacturing are many and varied. However, we have the utmost faith in the capability and ingenuity of U.S. manufacturers, and must together seek collaborative solutions to these challenges. The public sector must be an integral part of this process. There is much work to do to change the minds and hearts of policymakers and the public at large. It is our hope that this report contributes to this dialogue, especially with regard to understanding the increasingly networked nature of manufacturing, and the function of this evolving network in the development of new products and technologies.



ENDNOTES

[1]For example, even though layoffs have leveled out, we continue to hear about the 3.1 million jobs that have been lost since 2001; 36 percent of the 22 million manufacturing jobs at the 1970 postwar peak.

[2]Krugman, P. and R. Lawrence. 1994. "Trade, Jobs, and Wages." *Scientific American*. April.

[3]Whitford, J. 2006. *The New Old Economy: Networks, Institutions, and the Organizational Transformation of American Manufacturing.* New York: Oxford University Press.

[4]For example, General Electric cut its workforce by 40 percent, from over 400,000 twenty years ago to fewer than 240,000 in 1996, while sales increased fourfold, from less than $20 billion to nearly $80 billion over the same period. See Harrison, Bennett. 1994. *Lean and Mean.* New York: Basic Books.

[5]*Innovation, A New Reality for National Prosperity,* prepared by the 21st Century Working Group of the Council on Competitiveness's National Innovation Initiative, Dec. 2004.

[6]Fine, Charles. 1998. *Clockspeed: Winning Industry Control in the Age of Temporary Advantage.* Reading, MA: Perseus Books.

[7]See White, W.J., O'Connor, A.C., & Rowe, B. 2004. *Economic Impact of Inadequate Infrastructure for Supply Chain Integration.* Research Triangle Institute, prepared for the National Institute for Standards and Technology, Manufacturing Engineering Laboratory. May.

[8]For more information, see Eppinger, Steven and Anil Chitkara. 2006. "The New Practice of Global Product Development." *Sloan Management Review.* 47(4): 22-30.

[9]Unless otherwise indicated, this section draws heavily from Ulrich, Karl and Steven Eppinger. 2004. *Product Design and Development*. New York: McGraw-Hill. Furthermore, this was also informed by a seminar "Managing Complex Product Development Projects" sponsored the MIT Sloan School of Management.

[10]Cooper, Robert. 2001. *Winning at New Products: Accelerating the Process from Idea to Launch,* Perseus Books, Cambridge, MA.

[11]Replicated from p. 14 of Ulrich and Eppinger (2004) *op cit*.

[12]Ibid.

[13]Ibid.

[14]Ibid.

[15]Ibid.

[16]Ibid.

[17]Ulrich, K. 1995. "The Role of Product Architecture in the Manufacturing Firm." *Research Policy* 24: 419-440.

[18]Ulrich and Eppinger (2004) *op cit*.

[19]Norris, Guy, Geoffrey Thomas, et al. 2005. *Boeing 787 Dreamliner: Flying Redefined.* Perth, Australia: Aerospace Technical Publications International.

[20]Ibid.

[21]Ulrich and Eppinger (2004) *op cit*.

[22]Ibid.

[23]Computer models, along with other simulation techniques, significantly reduce the number of physical tests (but do not eliminate) needed with physical prototypes, thereby reducing the elapsed time and cost to validate a new product.

[24]Cusamano, M. and Kentaro Nobeoka. 1998. *Thinking Beyond Lean: How Multi Project Management is Transforming Product Development at Toyota and Other Companies.* New York: Free Press.

[25]Slade, B. 1992. *Compressing the Product Development Cycle: From Research to Marketplace*. New York: Amacon Books; Cusumano and Nobeoka (1998) *op cit*.

[26]According to Cusumano and Nobeoka (1998) "Companies struggle with how to bring back the learning that occurs within business units … furthermore heavyweight project managers can become too heavy: too few common components and too many unnecessary features and options exacerbating complexity in already complex products."

[27]Ibid.

[28]Ronald Coase was awarded the Nobel Prize for explaining that a firm exists to reduce transaction costs compared to individual market transactions. Transaction costs are comprised of the expenditure for "drafting, negotiating, monitoring, and enforcing a sourcing contract." Based on Coase's work,

economist Oliver Williamson posited that a firm's decision to outsource – the so-called "make or buy" decision – was primarily based on the cost of the transaction. Furthermore, transactions costs may increase due to information asymmetries as well as opportunism on the part of the firm's managers or suppliers. Williamson and other researchers of Transaction Cost Economics (TCE) seek to understand and explain these costs positing that – based on TCE – contemporary managers choose between vertical integration and outsourcing depending on which option economizes transaction costs. See Coase, Ronald; Williamson, O. 1979. "Transaction Cost Economics: The Governance of Contractual Relations," *Journal of Law and Economics,* 22: 233261 and (1985) *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting.* The Free Press, New York. See also Heriot, K. C. and S. P. Kulkarni. 2001. "The Use of Intermediate Sourcing Strategies." *The Journal of Supply Chain Management*: 18-25.

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[36]Other studies yield nearly identical results, highlighting the rapid gains in productivity in Japanese automobile manufacturers as compared to manufacturers in Europe and Great Britain. See Sako, M. and S. Helper. 1999 "Supplier Relations and Performance in Europe, Japan and the US: The Effect of the Voice/Exit Choice" in: Lung, Y., Chanaron, J.J., Fujimoto, T., Raff, D.M.G. (Ed.), *Coping with Variety: Product Variety and Productive Organisations in the World Automotive Industry.* Ashgate; Sako, M. and H. Sato. 1997. *Japanese Labour and Management in Transition: Diversity, Flexibility and Participation*, Routledge.

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[40]Womack et al. (1990) *op cit*.

[41]Thomas Stalkamp, a former Vice President for Chrysler, is credited with coining the term "extended enterprise" in his efforts to make Chrysler's supplier relations more collaborative. For more information, see Dyer (2000).

[42]Larson, P. 1994. "An Empirical Study of Inter-Organizational Functional Integration and Total Costs." *Journal of Business Logistics.* 15(1): 153-169.

[43]See Dyer (2000) *op cit;* and Dyer, J. H. 1996. "Specialized Supplier Networks as a Source of Competitive Advantage: Evidence from the Auto Industry." *Strategic Management Journal.* 17: 271-291.

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[56]The Sherman Act of 1890 made unlawful all contracts, combinations, or conspiracies to constrain trade. Though the Sherman Act is seen as the foundation for American antitrust policy, it lacked the enforcement mechanisms to constrain cartelization or monopolization. In 1914, Congress enacted two more major antitrust statutes to address the perceived policy shortcomings of the Sherman Act. The Clayton Act (also known as the Robinson-Patman Act) prohibited price discrimination, a practice whereby monopoly firms could extract more consumer surplus from customers by charging different prices to different classes of customers. The Clayton Act also prohibited tying arrangements and made it possible for the federal government to block anticompetitive mergers before they took place. The Clayton Act was later amended by the Celler-Kefauver Act and the Hart-Scott-Rodino Act, which set up an elaborate timetable requiring merger partners to notify the federal government of their intentions and articulate the competitive effects of the merger on the respective industry.

The other antitrust statute enacted in 1914 was the Federal Trade Commission (FTC) Act. The FTC Act established an agency headed by five commissioners to research and comment on the overall competitiveness of industry. The commission was given the broad mandate to prohibit "unfair means of competition and unfair or deceptive acts or practices." Generally, the "unfair means of competition" language has been interpreted as giving the FTC the authority to enforce the other antitrust statutes, including the Sherman Act. The FTC uses the "unfair or deceptive practices" language to prosecute firms engaged in fraud.

Antitrust enforcement was strengthened during the New Deal as the Roosevelt administration saw monopolies as a systemic barrier to perfect competition. Perfect competition is the theory that firms compete on price in the open market with fairly similar products. Subsequently, the prevention or dissolution of market power became a guiding principle of antitrust enforcement.

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[107]According to one Boeing official "90 percent of design is from the supply base as are 70 percent of the new technologies."

[108]For example, on the 777 there were 350 engineers working; on the 787 there are 79.

[109]While carbon fiber composites account for the majority of the "weight loss," an overall complexity reduction strategy will also help to reduce weight. For example, on the 777 there were 80 different computer systems; on the 787 there are 30.

[110]The first major maintenance (D-check) is scheduled for 12 years, opposed to 6 currently.

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1

DRAFT INTERVIEW/CASE STUDY TEMPLATE

YOUR COMPANY/DIVISION

a. History and Mission

b. What are your company's "core competencies"?

c. What are your products?

d. How do your products differ from your competitors?

e. What is the company strategy, where are you going in the future?

f. What are the biggest barriers to the success of your company?

INDUSTRY

a. History

b. What do your competitors say are their "core competencies"

c. What is the future of the industry?

d. What is the future of that industry in the United States?

e. Elsewhere?

f. What are the biggest challenges to the industry?

THE SUPPLY BASE

a. What is the approximate percentage of components manufactured by your suppliers?

b. How do you characterize your company/division's management philosophy toward its suppliers?
- i. What is the vision for working with suppliers?
- ii. Does this include all suppliers? Sub-tier suppliers? How do you differentiate?
- iii. What are the challenges to fully realizing this vision?

c. Please describe the responsibility of the "purchasing department".
- i. Please describe the skill set of your current department.
- ii. How does this compare with what is needed?
- iii. If there are gaps, how are you developing the technical competencies in the procurement organization?

d. What are the biggest challenges working with your suppliers? Are these different for different levels of your supply chain?
- i. How are problems identified and resolved?
- ii. What are biggest challenges for your suppliers to being a net-contributing team member?
- iii. What are the biggest challenges to your suppliers with regard to connectivity?

e. How do you evaluate/measure the performance of existing suppliers?
    i. How often do you review this?
    ii. Do you compare existing capabilities and competencies and compare them to future company needs?
    iii. Is cultural compatibility a consideration?
    iv. Is there a mechanism for suppliers to suggest improvements/add value to existing products?

f. Does your company provide development assistance to your suppliers
    i. If yes, how does your company determine which suppliers receive assistance and which do not?

g. Under what criteria do you select new suppliers?

PRODUCT DEVELOPMENT

a. What is the relationship between your company's strategy and the development of new products?
    i. How do you define your "targets?"
    ii. What are the metrics used for product development?

b. Please describe if and how your company conducts R&D. How is this linked into product development?
    i. What are the biggest technical challenges and how is this linked to your company's R&D strategy?

c. Does your company have an advanced product development group?
    i. Cross-organizational, cross-functional?
    ii. Do you/how do you involve purchasing?
    iii. Suppliers (see below for follow up)?

d. Does/How does your company use roadmapping to support new technology/new product development?

e. Does/How does your company evaluate the continuously emerging technologies in the marketplace?

f. Is/How is manufacturing linked in with product development, R&D?

g. How do you account for feedback from the end user in product development, manufacturing?

PRODUCT DEVELOPMENT WITH SUPPLIERS

a. Do/How do R&D, product development, and "purchasing" communicate during the product development process?

b. Do you work with your suppliers in the product development phase?
    i. If yes, when and how do you involve your suppliers?
    ii. How do you assess the technical competencies and capabilities of your suppliers?
    iii. How does your supplier selection for new product development differ from supplier selection once a product is introduced?
    iv. Do you have co-located suppliers, shared assets, joint investments?

c. Does/How does your company monitor suppliers, existing and potential, for emerging technologies?
    i. Do you/How do you account for supplier suggestions in the new product development process?
    ii. What about improvements to existing products?

d. Do you/How do you communicate customer requirements, product development targets, technical objectives, and other information to suppliers?
    i. Do you share future product plans with suppliers?
    ii. Do you share technology roadmaps with suppliers?
    iii. Do suppliers share their roadmaps with your company?

e. Do you have joint technology agreements with your suppliers?

f. Do you/How do you encourage supplier investment in new capabilities and commitment of resources in the long term to new product development efforts?

g. Given the question above with regard to supplier assistance, does/how does your company also help suppliers develop capabilities for integration into new product development – or any other kind of value-added assistance (marketing, etc.)?

POLICY ELEMENTS

a. Given your company's objectives, successes, and challenges with specific regard to working with your suppliers, developing products, or concurrent development with your suppliers:
    i. Has your company worked with any other organization – public, not-for-profit, consulting, or otherwise – to overcome these challenges?
    ii. Are there specific public policies/laws/infrastructure elements which support or detract from your company's efforts to become/remain competitive/address these challenges? If yes, what are they?
        1. In either case, how might specific public policies/laws/ infrastructure be improved?
    iii. Do you have any "outside-of-the-box" suggestions with regard to public policy on how federal and state governments might best support these challenges and trends?