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FROM BUYER TO INTEGRATOR: THE TRANSFORMATION OF THE SUPPLY-CHAIN MANAGER IN THE VERTICALLY DISINTEGRATING FIRM*

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Using case study data, we describe how a large personal computer manufacturer changed its supply-chain management strategy after outsourcing the majority of its design and manufacturing activities to a network of focused suppliers. To cope with this new structure, the firm created highly skilled generalists, "supply-chain integrators," who coordinate product development, marketing, production, and logistics from product concept to delivery across firm boundaries. We particularly focus on the skill-set that characterizes these integrators. Finally, we use the case evidence, combined with previous theory, to suggest a specific program of research into coordinating product development across disaggregated supply chains.
(SUPPLY CHAINS; NEW PRODUCT DEVELOPMENT; INTEGRATION; OUTSOURCING; ORGANIZATION DESIGN)

1. Introduction

"How do we manage the networks of suppliers we are building in order to stay competitive?" In our fieldwork on the management of supply-chains, we have heard this question at every firm we have visited. Firms as diverse as IBM, 3M, Dell, and General Motors are vertically disaggregating at an often blinding pace, delegating many of the activities they once performed in house to a network of specialist suppliers (Prahalad and Hamel 1990; Scouras 1996; Fung and Magretta 1998). In the authors' own conversations with these firms, however, operations managers have expressed to us that their existing models of supplier management are inadequate to the new business model. In this paper, we present exploratory case research from several industries, focusing on Hewlett-Packard (HP), a large and highly successful electronics and computer manufacturer that has recently shifted from a vertical to a collaborative product development model. In this collaborative model, HP, like many firms in recent years, has chosen an especially radical model of disaggregation by outsourcing everything *except* product integration. Thus, it must "design" products without having any traditional design—that is component—capabilities to leverage. In contrast, in the often-studied keiretsu model, assembly firms maintain the design of core components in house (Prahalad and Hamel 1990) and outsource the design of non-core components only to

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suppliers with whom they have decades-long relationships and mutual equity stakes (Clark and Fujimoto 1991). These conditions foster an atmosphere of well-understood and aligned mutual expectations enabling efficient and precise problem resolution (Fujimoto 1994). Disaggregated firms like HP, however, do not have the luxury to spend 20 years developing good supplier relationships. In our study of HP's notebook division, the organization had to make the successful transition from a vertical to a collaborative development model in less than 1 year. Yet, HP has apparently developed a successful strategy for managing the collaborative model. Interestingly, they appear to have done so by developing general management and technical skills in their personnel to integrate the specialist skills of their supplier networks.

The insufficiency of current models to address strategic imperatives in a context of temporary relationships led us to perform this exploratory case research. Our overarching question is how have firms successfully managed specialized, quickly changing supplier networks? The research at HP suggests that, although outsourcing significant portions of product development may provide competitive advantage, coordinating the outsourced pieces may indeed create new challenges in product development and procurement along the supply-chain interface. The research also suggests that dedicating employees to manage the interface can help meet these challenges. This new job, which we shall call the supply-chain integrator, differs radically from those found in traditional supply-management organizations, which have focused primarily on issues of cost, delivery, and inventory control. Instead, the supply-chain integrator, acting alone or in concert with integration colleagues, employs a mix of technical and business skills to coordinate, translate, and negotiate across the supply-chain interface to maintain the integrity of the product vision from initial concept to customer delivery. We then present the set of skills that managers at HP believe have helped their supply-chain integrators achieve this goal. We also present why HP thought these skills might be essential to guiding their new suppliers to ensure successful integration of suppliers' activities into a coherent final product or service. As will be seen, these skills overlap to some extent with the traditional product development toolkit, such as product development and systems engineering, but go beyond it to include such "hard" skills as operations management and information technology. Much more important, however, the successful integrator's skill set seems to also include such skills as project management, "soft" people management skills, and business case evaluation that are traditionally thought of as business rather than technical skills.

In Section 2, we review relevant papers from the product development, operations, and economics literatures. In Section 3, we discuss the methodology that we used in our descriptive and exploratory case analysis of HP. In Section 4, we present case study evidence to document the emergence of new types of supply-chain management systems for contract suppliers, analyze our data to argue for a list of desirable supply-chain integrator capabilities, and then consider these systems in light of predictions from the incentives and organizational behavior literatures. In Section 5, we summarize our findings at HP in order to present suggestions for numerous strands of future research including whether outsourcing development leads to special challenges for other firms than HP and, if so, how should these challenges be addressed. Finally, in addition to encouraging deeper research into supply-chain integrators, we also suggest investigation into task modularization and information technology as alternative or complementary methods to improve supply-chain coordination.

2. Previous Literature

Iansiti (1995a, 1995b, 1998, 2000), in his series of studies of the semiconductor industry, has unambiguously documented that, for firms to perform at a high level, technology integration is critical. He finds that those firms that invest heavily in a centralized technology integration capability substantially outperform those firms that allow integration to occur ad

hoc within research and development or manufacturing operations. Further, those firms that specifically address technology integration issues can succeed during times of architectural change, when most firms fail (Henderson and Clark 1990). Whereas Iansiti establishes the broad integration landscape, looking largely within firms, we focus more narrowly on the interface between firm and supplier, and on the types of people who staff these interface positions. We draw on a substantial literature from the field of product development and supply-chain management as we build our case for a new supply-chain integrator position and the skills necessary to do the job well.

2.1. *Product Design and Operations Management*

There is some evidence for the need to teach integration skills from other industries that have undergone fragmentation and found it necessary to integrate customers and suppliers into a network. In a study of the aircraft industry, Bozdogan, Deyst, Hoult, and Lucac (1998) find that proactively integrating key suppliers early in concept definition enhances the chances for architectural innovation. Key factors for this result include co-located product teams, long-term commitment to suppliers, joint responsibility for design, a seamless information flow (mechanisms that they do not fully define), and ongoing flexibility in defining system configuration. Coming near to our concept of a supply-chain integrator, Bozdogan, Deyst, Hoult, and Lucac mention (but do not explore in depth) the presence of government representatives, called advocacy teams, who are placed at each contractor to promote communication and trust. Jaikumar (1986) describes the 1970s breakup of the Italian textile industry. In his case study, a person emerges in the role of a supply-chain integrator, albeit with a different emphasis from HP's integrators. This person, whose function was also known in the 14th century, is described as an "impannatore," who "managed relationships with customers, shippers, and financial institutions." Fung and Magretta (1998) describe a very similar evolution in the Asian textile and toy industries. However, these impannatori operate in industries whose supply-chain management place relatively little emphasis on product design in comparison with the PC industry, which has a decisive influence on the skill mix underlying HP's integrators.

In a recent study that emphasizes the importance of properly managing organizational and design boundaries within firms, Sosa, Eppinger, and Rowles (2000) examine the development of a new aerospace engine within one firm. Of interest for our work, they find (1) that there is a strongly significant correlation between technical design interfaces and team interactions both within and across modules. This finding lends support for Loch and Terweisch's (1998) analytic predictions that highly concurrent tasks can use communication to offset the negative effects of rework. More relevant to the issues we are addressing, Sosa, Eppinger, and Rowles find (2) that team interaction, when there is a design interface, is less likely if there is also an intervening organizational boundary or system boundary; (3) that team interaction is more likely when there is a design interface if that interface is important (however, organizational boundary effects are even stronger); and, finally, (4) that the effects of organizational and system boundaries are more severe between modular systems than between integral systems. Allen (1997) also found a higher probability of communication between engineers when they share an organizational bond. Taken together, these findings suggest that properly managing the organizational boundary is critically important to successfully managing product development efforts, particularly for highly interdependent sub-assemblies.

With respect to managing the organizational boundary, Handfield, Ragatz, Petersen, and Monczka (1999) discuss the factors that go into choosing suppliers with whom to partner on product development activities. McIvor and McHugh (2000) discuss the organizational changes that go into working with suppliers more closely. Das and Narasimhan (2000) study "purchasing competence" and establish a positive relationship to manufacturing performance. Along with Fine and Whitney (1995), they suggest that "the basis of competition in

many industries in the future may revolve around the development of supply-chain competence by organizations." Further, Das and Narasimhan go on to emphasize the importance of purchasing integration. However, while these studies address integration broadly, they tend to focus on the design of a supply-chain network rather than the personnel and skills required to efficiently exploit the network once it is in place. In their survey of project management in plant design and construction (in which much of the detailed engineering work is outsourced), Davis-Blake et al. (1999) note that successful coordinators possessed business and "soft" people skills as well as a technical knowledge of construction and civil engineering. As will be seen, our research indicates similar results in outsourcing product development; however, we suggest that the mix of technical skills also changes when migrating from a vertical to a collaborative development environment.

Closs and Stank (1999) note that the supply of broadly trained supply-chain managers is scarce, and they describe the integrated supply-chain management program at Michigan State University as one step toward alleviating the shortfall. The program emphasizes manufacturing, purchasing, logistics, and information systems. Implemented in 1998, the program is too new to be judged a success or failure, but early results suggest substantial recruiter interest in graduates.

2.2. *Economics and Supply-Chain Management*

The two archetypal methods for organizing and integrating the design and production efforts of supply-chain partners—vertical integration versus contract suppliers—will help to shed light on the examples from HP. When a firm organizes design and production internally according to the multiple objectives of the firm (e.g., low cost, high quality, early time-to-market), the objectives of the organization are set for the layers underneath. At the project level, product managers wield fine-grained coercive power through organizational connections to engineers to ensure that these objectives are met. When a firm outsources, it contracts with supplier firms to provide design content and components or subassemblies for integration into a finished product (Holmstrom and Milgrom 1994). The objectives of this nexus firm may remain the same, but there has been a tendency for U.S. firms to use higher-powered incentives (e.g., direct pay for performance or awarding contracts to least-cost bidders) when dealing with external supplier firms than when working with internally owned supplier units (McMillan 1990).

Williamson (1975) predicted that firms would choose to vertically integrate when the potential for hold-up (through asset specific investments) exceeded the costs of foregoing strong incentives through arm's-length supplier relationships. Holmstrom and Milgrom (1991), however, show that when firms with multiple objectives use strong incentives, those tasks that are easiest to measure tend to attract the most effort, to the detriment of tasks whose output is more difficult to measure. For example, the cost of a component can be quite easy to determine, but product coherence and adherence to customer requirements are much more difficult concepts to define and measure. The traditional purchasing approach that emphasizes cost and delivery terms works well enough where specifications are clear and quality is easy to monitor. Once a supplier is involved in developing a product, however, the traditional approach is likely to fail because the objectives that are easiest to measure (e.g., cost, time-to-market) will attract the most attention, to the detriment of the other objectives of the firm (e.g., quality of design, product coherence). What we may be seeing at HP is that, while outsourcing is still favored to meet cost and time-to-market goals, there is the realization that suppliers must be managed more like the internal resources of the old vertically integrated firms than the old least-cost suppliers of years past that did no product design and built to exact specifications supplied by original equipment manufacturer (OEM) firms. One method to deal with the multiple-objective incentive problem is to dedicate people or organizations to handle supply-chain integration.

2.3. *Contribution*

We add to the literature by taking a detailed look at the skills that go into successfully managing the organizational interface across firms, especially during product development. Nevins and Whitney (1989) documented that 70% of the life-cycle cost of a product is determined during the product design phase in a number of industries. Clearly, improvements in product development are of paramount importance to firms. In our case studies, we closely examine how HP integrates a collaborative product development model. We also include some evidence from other firms in the electronics, automobile assembly, and semiconductor manufacturing industries that support or extend our findings at HP.

3. Methods and Data Analysis

We became aware of the position of supply-chain integrator as a result of our work on a different problem in late 1997 and 1998. The unique requirements of this position were so compelling that we shifted our research focus to further investigate this role in supply-chain management. Consequently, our early field-work was not geared explicitly toward understanding this role, although it addressed many facets of the position. From 1999 onward, however, our field-work has included an in-depth look at how firms are working with their suppliers to ensure product integrity through the design and delivery phase of the product life-cycle.

Our methodology can be described as an iterative descriptive and exploratory case study. In addition, by studying two subunits within one firm, we have an embedded case study within a single case. We drew on industry contacts and conducted a large number of interviews in an attempt to capture a detailed body of industry knowledge and practice with respect to supply-chain integration. Loosely following the grounded theory generation methodology pioneered by Glaser and Strauss (1967), we began the project with few theoretical priors. We developed a set of ideas about supply-chain integration that we explored in detail during subsequent interviews. To test for reliability in the data, each author analyzed the data independently in order to confirm that we were seeing the same integration phenomena.

3.1. *Data Sources*

Our story about the new role of the supply-chain integrator is developed from the following sources. (1) In 1997 and 1998, we were introduced to the changing role of the supply-chain manager through a series of 22 open-ended interviews at Hewlett-Packard. Between October and December 1999, we followed up with two additional in-depth interviews at Hewlett-Packard to explicitly investigate supply-chain integration. We augmented this knowledge base with interviews at BridgePoint (a semiconductor firm), a domestic automotive firm, and an office of the Department of Defense. (2) We made use of articles from the popular business press to delineate a contrast between industry practice in the early 1980s and today, and to further support conclusions drawn from our case study information. (3) Finally, we made use of other archival data, including HP reports and publications.

INFORMANTS. At Hewlett-Packard we interviewed individuals who have been with the company between 3 and 30 years. The majority of respondents had joined the company within the past 10 years. HP respondents were managers in the areas of product development, engineering, supply-chain management, procurement, or consulting services. At BridgePoint we interviewed both the CEO and the human resources manager. At the domestic automobile firm, we interviewed a mid-level executive responsible for incorporating systems engineering as a methodology at the firm. We also interviewed a former program manager at the Department of Defense who was responsible for overseeing the integration of mid-level launch vehicles and a military satellite system.

TABLE 1
Interview Questions Relevant to Supply-Chain Integration

Topic	Illustrative Questions
Product realization (1997, 1999)	Where is your product designed?
	Where is it manufactured?
	Who is responsible for maintaining product integrity?
	Who does systems trade-offs in engineering?
Supply-chain management (1999)	Is there any difference in the way you manage partners in the U.S. versus overseas?
	Who at the supplier works with the supply-chain management people at your firm?
	Who should staff this role at the supplier?
	Is managing the supply base a fun job?
Staffing and development (1997, 1999)	Where do you get people to staff the supply-chain integration function?
	If we were to design a supply-chain management program that focused on integration, what curriculum would you suggest?

Dates refer to when the questions were asked.

INTERVIEW QUESTIONS. Our interviews lasted an average of 1 hour each. When one interviewer was present, the data were captured by hand and then transferred to a computer record. When two interviewers were present, one interviewer concentrated on asking questions while the other took notes by hand or computer. In all interviews, we attempted to capture the responses verbatim. Table 1 shows the questions related to supply-chain integration that we asked of the interviewees. We did not ask every interviewee the entire set of questions shown in Table 1, but we interviewed the most productive people more than once. In 1997, subjects were interviewed for a project different from the investigation of supply-chain integration. However, the issue of supply-chain integration came through so strongly in the 1997 responses that we undertook this project in 1999 to follow up and expand on what we learned in the earlier study.

3.2. *Data Analysis*

Following Yin (1994), we assembled the written data and tabulated responses related to supply-chain management and the presence or lack of change in firm practice. From these responses, we developed a list of key issues in supply-chain management as practiced at the firms we contacted. We were particularly interested in how firms maintain product integrity as they distribute their product development function across a supply chain. We then contacted several respondents for follow-up interviews to clarify our understanding of initial impressions. After assembling the data set, we searched through the interviews in order to identify references to skills the respondents considered necessary for supply-chain integration.

In the next section, we use Hewlett-Packard as a focal firm to give readers a concrete example of supply-chain integration.

4. Methods for Organizing and Integrating the Supply Chain

In this section, we first describe examples from two divisions at Hewlett-Packard to show how one firm has addressed the problem of managing their supply base after extensive outsourcing. We then present the results of our data analysis from which we develop a supply-chain integration skill set. Finally, we consider some implications from the information processing literature to place the examples into a theoretical context.

4.1. *HP's Shift from Vertical to Collaborative Product Design*

Hewlett-Packard, a large manufacturer of electronics and computer equipment, has made a dramatic change in manufacturing strategy over the past 15 years. During the 1980s, this company was among the vanguard of U.S. firms advocating a renewed emphasis on domestic manufacturing. John Young, HP's former CEO, chaired the President's Commission on Industrial Competitiveness from 1983 to 1984. Miller (1987) reported Young's emphasis on manufacturing:

> Particularly, he [Young] declares, "we need to give manufacturing a more important role in company affairs. We've undervalued manufacturing in the mix of things we need to do as managers to compete in world markets." How to effect change in companies? "It's hard to come up with an answer . . . . But it's clear that two things go together—manufacturing and the associated human systems."

Today, Hewlett-Packard, the same U.S. electronics manufacturer that was among those calling for the rebuilding of U.S. manufacturing capability to counter the rise of Japanese manufacturing firms, has moved away from its previous "vertical" model of product development and delivery, in which it designed and produced many of its products' subcomponents, by divesting most of its manufacturing assets and product engineering capabilities. Instead, HP has adopted what we will term a "collaborative model" of product development and delivery in which suppliers do the vast majority of detailed design as well as manufacturing, while HP remains responsible for overall system performance. As an example of the personnel changes required by the shift from vertical to collaborative development, HP's Vancouver, Washington, division, responsible for ink-jet printers, eliminated 1,200 jobs in production while at the same time recruiting software and hardware engineers, Internet programmers and top-level marketing people (Brown 1999). An HP spokesman stated that the shift toward making Vancouver the North American hub for design and marketing while transferring production to outside contractors reflected a continuing trend in the electronics industry.

To understand how HP is managing its contract-manufacturing base under the new collaborative model, we interviewed employees in several divisions. The two divisions we discuss represent some of HP's fastest growing businesses: laptop computers and servers. The people interviewed for this study are involved in the design, development, manufacture, and sourcing of these two computer product lines.

MOBILE COMPUTER DIVISION. HP sources all of its notebook computer products from Asian manufacturers. HP's reasons for this change from the previous vertical model included the division's recent history of low revenue, low return on assets, and a high cost of sales. Additionally, HP had to annually divert between two and three million dollars from product development and marketing toward updating their capital equipment. And indeed, since they have adopted the collaborative model with Taiwanese notebook vendors, the division now has approximately 10 times the revenue and an improved cost of sales and return on assets. All of this occurred while reducing the number of employees from 400 to 50 (Parker and Anderson 1999). So how does HP manage this collaborative model of product development and delivery today? In general, Division headquarters generates design requirements while contract manufacturers perform the detailed design work and manufacturing (Parker 1997a; Parker and Anderson 1999). For laptops, the primary points of contact between HP and the suppliers are two supply-chain integrators whose duties overlap to a great extent. The first of these integrators they term a system manager, who must communicate specifications to the manufacturer and ensure a smooth design progress. Oversight of the supplier is then handed off to a delivery manager who oversees production ramp-up and customer fulfillment. Taken together, the system manager and delivery manager function as HP's supply-chain integration capability. They function in a high-pressure environment because the notebook product life-cycle is on the order of 6 months. The integrators serve both as the integration point

within the computer firm and as the contact people to the contract manufacturers. These managers must, without formal authority, reconcile the competing interests of multiple functions within the organization while also ensuring that the supplier's capabilities and constraints are factored into the firm's demands. That said, one person who held the delivery manager job reported that it was also "really fun, challenging, and rewarding." As we will explain, however, the skill mix of these integration people is very different from that of the skills of those employees who worked in the division just 5 years ago.

NETWORK SERVER DIVISION. In servers and workstations, HP also uses contract manufacturers to source its computer products. Wolfe (1998) describes how price pressure in the workstation market led HP's Network Server Division down a path similar to that of Mobile Computing. The server division undertakes only a little bit more work internally than does the notebook division, primarily in the area of cooling to ensure product reliability. Its focus is to manage the relationship with contract firms in the supply base. Robert Bowden, a senior manager in HP Corporate Procurement, described the migration from manufacturing for this division as follows: "It is unlikely that manufacturing people will grow up in line operations anymore. Instead, they'll be putting together supply networks and managing and evaluating external resources . . . . Our core competence is moving to the management of contract manufacturers" (Parker 1997b). However, he also observed that they did not have nearly enough people to manage these contract manufacturers. In particular, he cited the necessity for integrators to be able to consult as well as to negotiate, analyze, and build deals, and he commented on the scarcity of this skill set.

4.2. *The Supply-Chain Integrator's Skill Requirements*

As we approach the task of interpreting the data from our HP interviews, we draw on a substantial set of background interviews through our participation in a research project with Professor Charles Fine and Dr. Daniel Whitney of the Massachusetts Institute of Technology, during which we visited many firms [including the Chrysler Corporation (Daimler-Chrysler), the Ford Motor Company, General Motors, Cincinnati Milacron, Bihler USA, Detroit Center Tool, Progressive Tool, Giddings and Lewis, Leblond-Makino, NipponDenso (Denso), Toyota, Applied Materials, Intel, and many others] over the period of 1993 to 1996. These visits were part of the supporting research for an investigation of the development of corporate technology supply chains (Whitney 1993; Fine and Whitney 1995; Fine 1998, 2000). We also use our own experience as engineers and project managers at General Motors (Anderson, 1985 to 1987), Ford Motor Company (Anderson, 1988 to 1993), and General Electric (Parker, 1985 to 1990). We have repeatedly turned to our former industrial colleagues in these firms to help clarify the issues we observed in our case and archival data.

In our case studies at HP with the two divisions just described, two main themes emerge from HP's shift from a primarily vertical product development model to a collaborative product development model. First, while collaborative development may, as HP's examples suggest, require many fewer employees than vertical development, there is still a need for a new infrastructure to support collaborative product development (Parker and Anderson 1999). Under the new model, suppliers perform the bulk of product and process development. This eliminates numerous HP employees performing such detailed design tasks as circuit and package design. However, HP still maintains overall design integration and some bits of detailed development in order to guarantee the reliability and user-friendliness associated with the HP brand. This shift required Hewlett-Packard to develop an effective method to meld together their suppliers' development capabilities, which was previously unnecessary. To do this, they needed to radically change the skill set of the personnel that remained in product development. For example, in the past, an HP product development engineer would typically be deeply skilled in circuit design, software engineering, packaging, testing, or some other detailed design domain but would leave purchasing negotiations to a dedicated

purchaser. The purchaser, in turn, would typically have an MBA and some technical background; however, he or she would refer the few necessary detailed technical questions to the design engineer.

In the collaborative model, suppliers perform detailed design. Thus, to deliver the product, HP needs supply-chain integrators who can maintain product coherence from concept to customer across often numerous firm boundaries. This shift makes the product designer's emphasis on detailed design skills redundant. (Advising purchasers can be handled by a few high-quality technical specialists, which as will be seen, HP in fact does.) Under collaborative design, an integrator does not need to know how to design a motherboard; rather, he needs to know how to assess the financial and technical implications of a *supplier's* motherboard design with respect to other product subsystems—perhaps from other suppliers—to maintain the HP look and feel of the project. Furthermore, the integrator must ensure that the supplier makes any necessary changes to its design. While an old-style product engineer's skill set may help in these tasks, it is insufficient because the "soft skills" necessary to motivate change and the business evaluation skills required to assess change are missing. Similarly, while an old-time purchaser's skill set may be helpful in evaluation and negotiation, it too is insufficient because of the many technical issues involved. Finally, our interviews with HP employees suggest there may be additional critical skills in managing collaborative development that go beyond either old-style product engineer or purchaser. As one manager said, "We needed a whole new group of people, and we didn't have a clue how to do it effectively. A year later now we're good at it. We can now spend money on being first to market and differentiation that the customer values. We're going to be first with Windows 2000" (Parker and Anderson 1999).

The skills that our interviewees believed helped the new integrators achieve these demanding goals under a collaborative product development model constitute the second theme of our interviews. They are listed in Table 2.

Note that this list of skills should not be construed as an exhaustive set of all the capabilities that supply-chain integrators might need. Instead, this list may be thought of as a point of departure for further study into the human resource implications of supply-chain integration. The skills that emerged from our research fall broadly into three categories. (1) Project execution—including both the "hard" and "soft" skills to make sure the product is delivered with acceptable cost, quality, and timing; (2) project evaluation—estimating the cost and performance trade-offs inherent in the design in the midst of a complex business

TABLE 2

Summary of Supply-Chain Integrator Skills Taken from HP Interviews

Skills	Short Description
Project execution	
"Hard" project management skills	Setting objectives, milestones, and contingency plans.
"Soft" project management skills	Persuasion, negotiation, mediation, translation, "identifying and exploiting people's strengths while improving their weaknesses."
Product development	Maintaining product integrity from concept to customer, decomposing product into modular subunits, specifying module interfaces.
Project evaluation	
Systems engineering	Making subsystem technical trade-offs.
Business case evaluation	Identifying and balancing costs vs. business objectives.
Complexity management	Identifying the few critical constraints and trade-offs from a complex business problem.
Related domain knowledge	
Operations management	Process analysis, process improvement, basic supply-chain theory.
Information technology	How information technology enables operations.

environment; and (3) related domain knowledge—domains that the integrator must broadly understand in order to execute and evaluate the development project. Clearly, this skill set contains a diverse set of both technical and non-technical abilities. However, the skills have a common thread in that they emphasize boundary spanning and problem definition. Below, we define these skills, identify why HP thinks they are necessary, and then elaborate on them using theory drawn from product design, economics, and organizational behavior theory as well as from observations from case studies of other select firms.

4.3. *Arguments and Evidence for the Skill Set*

4.3.1. PROJECT EXECUTION. *Project management.* At the root of the change from vertical development to collaborative development, the bulk of HP's internal product development effort shifted from product design to project management. This is because, while most of product design is outsourced, project management remains internal to HP. Furthermore, several HP managers noted that project management becomes even more complex than in the vertical model because, as a manager of supply-chain integrators in the mobile computer division described, "the [supply-chain integrator] job is very difficult—you have no direct reports. You lead without a big stick." Clark and Fujimoto's (1991) taxonomy describes a program manager as "heavy" or "lightweight" depending on how much direct versus "dotted-line" control a project manager had over his resources. It is important to note that Clark and Fujimoto were referring only to reporting relationships within a firm. In contrast, the relationship of HP with its supplier engineers crosses not only organizational but also corporate boundaries, leaving integrators with only the most tenuous authority over their detailed-design staff. Hence, HP's integrators could effectively be analogized in Clark and Fujimoto's terms as "flyweight" managers. To overcome this disability requires both "hard" planning skills and "soft" boundary-spanning skills. From a technical or "hard" perspective, HP management believes that "being really good at setting plans and objectives is more crucial [with suppliers than within HP]. You need to be a better manager than before. They're forced not to micromanage. You can't just walk down the hall to get involved" (Parker and Anderson 1999). The ability to formulate clear goals is crucial because their supplier resources are typically distant in geography, time, and culture. For example, most of HP's partners are in Taiwan, which has a 14-hour time zone separation from Hewlett-Packard in Santa Clara, California. Thus, if a question about project direction arises, it will take at least one business day to resolve. Hence, avoiding these questions is crucial to compressing development timing. To minimize problems, HP integrators find that the ability to develop contingency plans is a crucial skill. In a fast-paced industry with 6-month product life-cycles, if a Taiwanese supplier's prototype test fails because of a missing part, integration relationships should allow the supplier to act without wasting time waiting for specific HP instructions. Micromanagement is typically counterproductive because the integrator cannot "just walk down the hall" to determine the detailed status of each project task. To do this effectively, one would have to force the vendors to write very detailed daily reports that at best would still give an incomplete picture of the development effort and would clearly reduce the productivity of the vendor's engineers. At worst, micromanaging based on incomplete or inaccurate project status information would drive the vendors to make many mistakes, again wasting precious time. All of these factors taken together place a premium on managing by very clear objectives and milestones while avoiding micromanagement.

"*Soft*" *people skills.* In addition to the "hard" skills of project management necessary to get "multiple firms going in the same direction," integrators also need to compensate for the gap in hierarchies and cultures between HP and its suppliers. As one manager stated, "You get lots of responsibility, but little authority" (Parker 1997a). Because the integrators must, in another manager's words, "lead without a big stick [to cope with] the high pressure and conflicting requirements" of product development (Parker 1997a), they must instead wield a "little stick" of people management skills to ensure results. Furthermore, they must do this,

as the same manager states, "without burning bridges." For example, if there is a conflict with a vendor regarding a design change, the integrator could simply order the supplier to implement the change without explanation. This might not work, however, because there is no formal authority over the vendor's engineers, and HP is unlikely to stop using a supplier for any one particular transgression. Also, the resulting conflict could lead to the loss of valuable time and perhaps trust. An integrator's ability to engender mutual trust with suppliers is critical to facilitating this type of joint problem solving (Currall and Judge 1995; (Zaheer, McEvily, and Perrone 1998). What HP integrators have typically found preferable is to "put together compelling arguments to sell an approach" to their vendors and, when all else fails, to negotiate with them. Furthermore, there is a need to mediate and translate imperfect technical requirements and objectives from the technical and institutional context in one firm to another. This is expressed most starkly in the fact that half of HP's notebook division integrators speak Mandarin (Parker and Anderson 1999). Although in theory this may be unnecessary because most of the vendor's Taiwanese engineers speak some English, it still helps avoid misunderstandings concerning objectives that could evolve into significant problems. Communication problems are exacerbated because direct telephone contact is difficult to arrange on an ongoing basis and, because of the language barriers, the preferred mode of communication is by e-mail. [HP's reliance on e-mail is not unusual. Sosa, Pich, McKendrick, and Stout's (2000) study showed that reliance on e-mail across firms with different first languages is a common phenomenon in product development.] As an interesting bit of evidence for the importance of such managerial soft skills, over half the integrators at HP are former mid-level engineering managers who were characterized as being highly skilled at "the management of people," particularly "exploiting people's strengths and [improving] their weaknesses" and "negotiation" (Parker and Anderson 1999).

Product development. The purpose of the project management process just described is to develop and deliver a product from concept (which is a set of imperfect specifications derived from the market) to the customer in a period of 6 months. To do this requires, as stated earlier, a combination of hard and soft project management skills. But these skills are useless if the integrator is not also skilled in the appropriate domains needed to clearly articulate the project's objectives and understand the vendor's issues. As one manager described the design process, it is "done jointly here and with the [Taiwan contract manufacturing] partners" (Parker and Anderson 1999). Hence, in order to manage the project effectively, several areas of technical domain knowledge are needed. In particular, HP integrators believe that they need a deep understanding of certain higher-level aspects of product development. These include (1) translation of customer requirements faithfully into a product concept and maintaining its integrity over time [see Iansiti and Clark (1994) for a fuller description of product integrity]; (2) life-cycle planning; (3) architecture definition (including system decomposition, which breaks the product into modules); and (4) interface specification (to connect the subunits back together). As in any other model of product engineering, a deep understanding of translating customer wants into a design intent that can be clearly articulated to other involved parties is crucial; otherwise, the product designers will design to specifications that do not reflect customers' needs, and thus the final product will miss the market (Griffin and Hauser 1993). Given the translation problems across firm boundaries discussed earlier, this may even be more critical in the collaborative product design model than in the vertical model.

Given that HP's goal is to turn over their product portfolio every 3 years, design must be performed in a short period of time, which makes life-cycle planning necessary to provide the milestones for the "hard" project management skills discussed earlier. Another way product design skills support project management is that, similar to any other project manager, much of the integrator's efforts are taken up with managing the conflicts that arise between HP and its vendors, or between the vendors themselves. To the extent that the integrator can manipulate the product architecture to decompose the project into independent stand-alone

modules with a minimum of interconnections at each interface, he will reduce the number of necessary interactions between firms. This will in turn eliminate the number of future mediations and negotiations necessary for the integrator and should reduce development time.

Product decomposition skills also assist the integrator in ensuring that product reliability and quality meet HP standards. Or, as one manager stated, "'HPizing' [that is, building in reliability and user-friendliness] happens at HP" (Parker and Anderson 1999). In recent years, the bulk of quality problems have shifted from component-level issues to systems-level issues that cut across vendors (Rajgopal, Mazumdar, and Mejety 1999). For example, HP held it vitally important that they were first-to-market with a Windows 2000–compatible notebook *that worked.* Without the ability to clearly hold on to this vision and subordinate all other issues, the product could very easily fall prey to the different design agendas of various vendors, such as introducing the latest Pentium microprocessor or introducing a new longer-lived battery technology. Being sidetracked by these issues would have either watered down the key advantage of this product for HP's customers, the ability to run the new operating system flawlessly, or delayed launch time for their product, thus causing them to lose first-mover advantage.

4.3.2. PROJECT EVALUATION. One of the major duties of integrators at HP is "trading off design improvements versus manufacturing costs and hurting schedule" (Parker and Anderson 1999). As will be shown, this duty requires a combination of technical and business skills.

Systems engineering (*subsystem trade-off ability*). While we believe that systems engineering is essentially an extension of product development skills, it is often taught separately at the university level and is sufficiently different from what is normally considered product design capabilities, such as circuit and packaging design, and so on. Essentially, trading off cost, quality, and timing reduces to a "dollarization" of each of the contending project imperatives. The people HP thought were good at this are "good R&D people who did it before. Some were start-ups in the Valley who ran things on a shoestring budget and borrowed and stole to get things done" (Parker and Anderson 1999). An integrator who is skilled in systems engineering will possess the technical ability to perform these evaluations, so that he or she can effectively influence the design choices that are made at both the subsystem and system levels.

Business evaluation. In addition to product development and systems engineering skills, several managers at HP emphasized the need for supply-chain managers to be able to evaluate supply-chain options on their financial merits. For example, one HP manager recently had to analyze the implications of build-to-order versus build-to-stock supply decisions for the manager's business (Parker 1997a). Another figured out several suppliers' pricing models, which allowed him to show what jobs should be given to which suppliers in order to minimize cost (Parker 1997a). Other managers have had to include currency fluctuation estimates in their supply-chain decisions (Parker and Anderson 1999). Doing so required HP to develop an integrated financial and technical picture of supplier development capabilities. Without an adequate background in corporate finance and costing, the integrators would have been unable to perform these tasks.

Complexity management. Additionally, HP articulated a need for supply-chain integrators to be able to manage complexity and ambiguity. As HP manager Robert Bowden noted, "There is still a mindset based on manufacturing. We need to understand supply networks in extremely complex, global environments. It is challenging to find people who can deal with complexity" (Parker 1997b). He also observed, "It is unlikely that manufacturing people will grow up in line operations anymore. Instead, they'll be putting together supply networks and managing and evaluating external resources." In the test and measurement division, a manager observed, "We need people who can think across the supply chain—big-M [this

term includes product design and logistics as well as what is traditionally considered shop floor manufacturing]" (Parker 1997a). The need to be able to handle complexity is hardly limited to people staffing supply-chain management and integration roles. However, these are positions where changes in manufacturing and supply-chain strategy are immediately felt. Supply-chain configurations and their implications in a global environment can be quite fluid, as in the earlier HP Notebook Division example where the entire strategy changed from internal production to contract manufacturing in just 1 year. Instruction on how to reduce complexity and ambiguity to concrete plans and decisions is not typically given in engineering schools. However, learning these skills is one of the standard goals of the case-based teaching method that one encounters in business school education. So, the resources to deliver instruction for complexity management exist at many universities if business and engineering teaching resources can be somehow combined.

Relationship between technical and business skills. The complementary abilities to evaluate business cases and system trade-offs are necessary to guide the integrator in solving the inevitable product development and sourcing problems in such a way as to maximize customer value and firm profit. Integrators need not know how to evaluate all the fine points of each problem themselves. Knowing all the possible technological ramifications of every possible problem as well as being expert in project management and soft people skills would require a superhuman. The solution favored by HP (and many other firms that use systems engineers) is to hire specialized technical experts to advise front-line integrators when they must handle especially challenging technical problems. For instance, HP's notebook division employs several such troubleshooters with deep technical expertise in electronics miniaturization. According to a manager in the notebook division, most of these experts "were small hardware designers at HP for a long time. People who designed calculators in the '70s and palmtops" (Parker and Anderson 1999). Thus, while it is imperative that integrators have the general skills of an MBA and systems engineer, they need not know in depth all the technical fields with which they interact.

4.3.3. RELATED DOMAIN KNOWLEDGE. *Operations management and information technology*. Supply-chain managers have told us that a good grounding in operations management and information technology is essential. As one manager said, "What you need is Operations Management 101. Basic logistics, what a Material Requirements Planning (MRP) system is, et cetera. For what we're doing, the shop floor work is not as applicable, but [understanding] quality processes [is important]" (Parker and Anderson 1999). Another respondent also cited process analysis as key. Again, as with product design, the core concepts must be understood. For the more esoteric aspects of specific areas such as logistics, they can request technical assistance from an operations research or manufacturing technology group. Without a good understanding of the possibilities inherent in operations management, however, they will not know what questions to ask suppliers or which possible solutions to evaluate. Finally, a basic knowledge of the possibilities inherent in modern information technology is necessary to the integrator. This may surprise the reader (as it did the authors!). The HP managers stated flatly, however, that they could not change any current operational process without considering the information systems impact. An example cited was that a change in the logistics of one notebook model required a significant modification of their information systems.

> For example, we need to interface HP with Taiwan. We have two partners there. We want to go to one third-party warehouse for risk-pooling purposes. We need to stitch them together. You need a cursory understanding of what tools are out there and what's possible. . . IT touches everybody in the organization. Part of Dell's success despite its vertical integration (sic) is they're really good at IT. They've invested in it, and it's paid off (Parker and Anderson 1999).

There is evidence that the need for integrators to possess general information technology (IT) skills may hold true not only for HP or its supply-chain integrators, but for operations managers across firms in general. Bozdogan, Deyst, Hoult, and Lucac (1998) also note the

importance of IT in achieving architectural innovation with supplier involvement. Yang and Papazoglou (2000) and Abdalla (1999) emphasize the role of IT for effectively working with suppliers on new product development projects and for ongoing business operations. Again, as with the detailed product design skills, while the actual IT applications can be developed by specialists—perhaps outside HP—the integrator's knowledge of what supply-chain strategies IT can and cannot enable is essential.

5. Conclusion and Suggestions for Future Research

From our study of Hewlett-Packard and a number of other firms, we have learned that difficult supply-chain integration issues appear to occur frequently enough to justify specialized methods and resources, such as supply chain integrators, to knit the pieces of the outsourced product development process back together into a coherent whole. However, our exploratory research into how to outsource development most efficiently must be understood within the larger strategic context of outsourcing. In particular, future researchers might consider the supply-chain integration issue within a sequence of three inter-related research questions. (1) Are there challenges in product development created or complicated by outsourcing large portions of product design? (2) Do dedicated personnel for integrating product development along the supply-chain interface aid in meeting these challenges, or are other methods more appropriate? (3) If dedicated personnel are most appropriate in a given situation, then what skill set should they possess?

One way to approach the first research question is to consider Galbraith's (1973) classic work on how information is processed within a firm. It argues that the main ways a firm makes decisions are through (1) corporate rules and standard operating procedures, (2) referring problems to someone higher in the hierarchy, and (3) management by objective. Our research with HP suggests that outsourcing product development compromises the first two of these methods because HP's vendor firms will typically have different rules and standard operating procedures, and there exists no common hierarchy across the supply chain to which to refer problems. But how generalizable are these results? And does management by objective become easier or more difficult across supply chain boundaries? Research quantitatively documenting all these issues across a broad spectrum of firms would prove of great benefit.

Galbraith's work can also be used to more fully detail the second research question. In particular, he suggests that there are four methods of improving organizational decision-making whenever problems arise that cross organizational boundaries. They include the following:

1. Accepting performance degradation. This may perhaps be a financially sound option in some circumstances. If so, under what circumstances should a firm follow this counter-intuitive strategy?

2. Creating modular tasks. This method has been a staple of the electronics industry for decades (Fine 1998), but how well would this transfer to more integral products such as automobiles or airplanes?

3. Investing in boundary spanning personnel to glue the system back together. From our exploratory research, this appears to be HP's primary model of improving integration. However, will this solution work well for other firms?

4. Investing in information systems to knit an industry together by enforcing standards such as the automobile industry's Covisint e-business hub (Davis 2001). This solution seems to have great promise, but do any successful examples of this solution currently exist, and, if so, how successful are they?

Research toward understanding the strengths and weaknesses of each of these individual methods and under what conditions each is most appropriate would be of immense value.

Finally, with respect to the third research question, HP seems to have solved many of its

supply-chain coordination problems by investing in dedicated and specialized management personnel, whom we have termed supply-chain integrators. Assuming that such a policy can be successfully applied to other firms, there arises yet another research issue of interest. In the long run, obtaining new integrators may prove problematic because HP, like many other companies with which we have spoken, currently recruits its core of integrators from veteran engineers and managers who have held multiple positions in product design and manufacturing over the past 20 years (Parker and Anderson 1999). Although this is a quick and efficient method for obtaining integrators, it will become increasingly less viable as the vertically integrated firms—such as HP—that created these veterans disaggregate. Hence, in the long run, educational institutions will have to meet the demand for integrators by producing personnel who, directly, or almost directly, out of school, have the necessary skills to integrate a supply chain. But what exactly should these skills be? As described in the earlier literature survey, guidance from the literature appears to be largely absent. Guidance from academic practice is also problematic. While some institutions have made progress toward delivering integrated supply chain programs (e.g., Michigan State University, Pennsylvania State University, MIT) and some of them have become popular at the undergraduate and graduate levels (Closs and Stank 1999), these programs continue to focus on the tactical delivery of products and services rather than the ongoing task of renewing those products and services. This focus may be insufficient as supply-chain relationships expand beyond traditional collaborative manufacturing or delivery to embrace collaborative development. As noted earlier in the paper, Nevins and Whitney (1989) established that on the order of 70% of the life-cycle cost of a product is determined during product development, so the competence with which firms develop products and services in conjunction with their suppliers is of tremendous importance. Hence, many current programs may require modification in order to meet the challenge of vertically disintegrating firms. Thus, a research issue of the highest importance is to determine what should a program to train supply-chain integrators look like and what skills should it emphasize. As a first step toward filling this void, this paper has described the skill set that one firm believes may enable effective supply-chain integration. In particular, by possessing technical, business, and interpersonal skills, HP's personnel seem able to translate and mediate technical specifications among suppliers to maintain the integrity of its product vision, thus spanning the traditionally separate domains of product functionality, logistics, and cost. One potential method to deliver these skills may be to somehow combine a degree in systems engineering with an MBA oriented toward product design and operations management. However, before any educational programs are implemented to develop supply-chain integrators, more detailed and rigorous studies should be undertaken across a broad-based sample of firms to ascertain the appropriate skill set to teach.[1]

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