Global Strategy Journal
Global Strat. J., **3**: 41–66 (2013)
Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1111/j.2042-5805.2012.01050.x

MANAGING A GLOBAL PARTNERSHIP MODEL: LESSONS FROM THE BOEING 787 'DREAMLINER' PROGRAM

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Little research has examined the integration challenges in globally disaggregated value chains in a complex NPD effort or the tools managers use to overcome such challenges. Drawing on Boeing's 787 program, we highlight integration challenges Boeing faced and how it addressed them through recourse to partial co-location, establishing a centralized integration support center, reintegrating some activities performed by suppliers, and using its bargaining power to facilitate changes. The integration tools Boeing employed were geared toward two primary objectives: (1) gaining increased visibility of actions and visibility of knowledge networks across partner firms; and (2) motivating partners to take actions to improve visibility. These findings add empirical traction to the theoretical debate around the integration tools and the role of authority in the knowledge-based view of the firm. Copyright © 2013 Strategic Management Society.

INTRODUCTION

How do firms integrate knowledge in a globally distributed new product development (NPD) effort involving cutting-edge technology? Addressing this question is important because value chains in numerous industries have become increasingly globally disaggregated (Mudambi and Venzin, 2010). Also, firms are locating NPD and R&D activity in offshore locations to leverage knowledge and talent (Lewin, Massini, and Peeters, 2009; Thursby and Thursby, 2006). Such trends have increased the importance of integrating globally sourced external knowledge with internal firm knowledge and capabilities.

The importance of integrating is especially true for firms engaged in strategic NPD activities that often rely on external sources such as suppliers and customers for specialized knowledge. With increasing complexity, rapid technological advance, and widely dispersed knowledge and expertise, it is difficult for any single firm to internally assemble the knowledge needed for complex NPD projects. Instead, firms must depend on external innovation partners to build products within acceptable budgets, timelines, and financial risk (Chesbrough, 2003; Madhok, 1997; Powell, Koput, and Smith-Doerr, 1996). Typically, in order to develop high value products or services, firms must acquire external knowledge and effectively integrate it with internal knowledge (Becker and Zirpoli, 2011; Dyer and Hatch, 2006; Wadhwa and Kotha, 2006).

Past research has shown that integrating knowledge across geographies can be difficult (Bartlett and Ghosal, 1989; Meyer, Mudambi, and Narula, 2011; Mudambi, 2011), especially from foreign suppliers and alliance partners (Almeida, Song, and Grant, 2002). This is because tools such as normative integration, social integration, and authority

Keywords: global integration; qualitative study; activity and knowledge visibility; knowledge-based view of the firm; disaggregated value chains
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relationships (Bartlett and Ghosal, 1989; Martinez and Jarillo, 1989; Rugman and Verbeke, 2009) used by the multinational enterprise (MNE) to integrate activities across geographies are unavailable in *globally disaggregated* buyer-supplier supply chains (Rugman, Verbeke, and Nguyen, 2011).[1] Although (partial) co-location or significant travel across the globe is theoretically feasible, it is prohibitively expensive in practice, forcing firms to consider alternatives. As well, the need for specialized external sources of knowledge may require a buyer to work with suppliers with the requisite knowledge but no prior relationship.

Understanding how to effectively integrate knowledge among the subsidiaries of an MNE is one of the most important research areas in global strategy (Kogut and Zander, 1993; Mudambi, 2011). However, little research has examined the integration challenges in *globally disaggregated value chains* in a complex NPD effort involving cutting-edge technologies or the tools used by managers to overcome these challenges. This study attempts to address this gap by exploring the question of *how a firm integrates globally disaggregated new product development and manufacturing*. To address this, we identify the components, tools, and mechanisms that underlie global integration capability.

Since the research question addresses issues pertaining to a globally disaggregated complex NPD initiative, we chose a setting in which such processes are still unfolding. To this end, we examine Boeing's 787 *Dreamliner* program. The 787 airplane is a breakthrough product involving cutting-edge technologies, which required a significant integration effort between suppliers and Boeing locations across the globe. The 787 airplane represents a breakthrough product because it is the first passenger plane built using composite materials, which pushed the technological frontier in terms of flying a certain distance with 20 percent less fuel than comparable planes.

We undertook a qualitative study of this globally distributed, complex NPD project because the introduction of a new airplane provided the ideal context for examining issues in global supplier integration. We explore the different types of integration challenges faced by Boeing in the 787 program, and observe how these issues were resolved in order to uncover the building blocks of a global integration capability. Integration in this context takes place in an unstructured setting laden with ambiguity, which makes it difficult to specify interdependencies across firms and geographic boundaries *a priori*. In addition to the role played by traditional mechanisms that drive integration, the chosen context allows for other potentially interesting mechanisms to be identified and discussed. This is best accomplished using a qualitative approach (Eisenhardt and Graebner, 2007).

Our findings suggest that Boeing encountered three kinds of integration problems in implementing the 787 airplane program. It achieved integration through recourse to partial co-location, established a unique IT-enabled centralized integration support center, reintegrated some activities previously performed by suppliers, and used its bargaining power to facilitate integration. We found that the integration tools employed were geared toward two primary objectives: (1) gaining increased visibility of actions and visibility of knowledge networks across partner firms; and (2) motivating partners to take actions that would improve visibility. These findings contribute to our understanding of the components of a global integration capability and add a level of empirical traction to the largely theoretical debate around the role of authority in the knowledge-based view of the firm.

Background literature

An extensive amount of international business research has considered the difficulty in integrating knowledge across locations *within* an MNE (e.g., Mudambi, 2011; Rugman and Verbeke, 2009). In contrast, we focus specifically on knowledge integration *across* geographically distributed buyers and suppliers involved with complex NPD programs in a global setting. In general, integrating knowledge-intensive activities between firms is more difficult than within a single firm because personnel from different firms lack a: (1) common language, common culture, or agreed upon decision principles that arise naturally within firms (Grant, 1996; Kogut and Zander, 1992, 1996); and (2) unified source of authority to enforce decisions or break deadlocks that arise from conflicts (Williamson, 1985).

Prior work suggests that buyer-supplier relationships achieve knowledge integration by broadly relying on three sets of tools: (1) co-locating buyer

[1] Normative integration provides benefits such as a common language and agreed upon decision rules (Ghoshal and Nohria, 1989), whereas social integration enables the transfer of sticky knowledge through strong ties (Frost and Zhou, 2005; Hansen, 1999, 2002).

DOI: 10.1111/j.2042-5805.2012.01050.x

and supplier engineers (Dyer, 1997; Dyer and Nobeoka, 2000; Helper, MacDuffie, and Sabel, 2000); (2) leveraging relationship-specific assets (RSA) developed in prior interactions (Dyer and Singh, 1998; Kale and Singh, 2007); and (3) using modular product architectures (Baldwin and Clark, 2000). Such tools have significant shortcomings when integrating knowledge in buyer-supplier NPD relationships that are *globally* distributed, as will be explained below.

Co-location and integration

One approach to integrating knowledge between buyer and supplier engineers is through co-location, at least for the critical phases of a project (Dyer, 2000; Lincoln and Ahmadjian, 2001; Olson and Olson, 2000). Dyer and Nobeoka (2000) have shown that geographic proximity is a key consideration in creating supplier groups in the Toyota network. Typically, Toyota has engineers from its suppliers working in its facilities for extended periods, and vice versa, leading to human capital co-specialization (Dyer, 1996; Dyer and Nobeoka, 2000). Operating within the same environment facilitates the emergence of shared contextual knowledge, which in turn, promotes integration (Kraut *et al*., 2002; Olson *et al*., 2002).[2] Helper *et al*. (2000) argue that co-location supports monitoring and promotes socialization between buyer and supplier employees, leading to superior integration outcomes. In short, co-location facilitates effective integration.

However, in globally distributed NPD projects, (partial) co-locating supplier engineers and/or facilitating extensive travel across the supplier network is prohibitively expensive in practice, leading firms to look for alternatives to achieve integration. Also, in globally disaggregated projects, differences in language, culture, and institutional diversity further exacerbate the coordination problems that arise due to geographic distance such as the lack of frequent, rich situated interactions between interdependent agents.[3] It is important to note that whereas prior work has pointed out the problems arising from geographic dispersion, it is still an open question as to how such relationships should be managed to achieve effective integration between the assembler and suppliers when co-location is constrained.

RSA and integration

Research suggests that when exchange partners develop RSA, or relational capital, they are more effective in integrating activities (Doz, 1996; Dyer and Singh, 1998; Kotabe, Martin, and Domoto, 2003). Relationship duration influences the stock of RSA between partners, with the current project benefitting from learning in prior interactions. As partner-specific experience and learning accumulate, they create RSA such as the development of a common language, interaction routines, and a better understanding of partner decision-making procedures, leading to better knowledge exchange and superior integration (Dyer and Singh, 1998; Gulati, Lavie, and Singh, 2009). RSA among established partners could include aids in achieving integration in NPD, such as boundary objects that can convey meaning across different functional specialists (Carlile, 2002) and the presence of boundary spanners with the recognition and credibility across the different units (Mudambi, 2011).

In globally distributed NPD projects involving cutting-edge technologies, RSA may be unavailable or severely constrained. First, the necessary technological know-how may be available only through firms that share no prior relationship (Garud and Munir, 2008). For instance, when electronics technology was incorporated into cars, automotive manufacturers were forced to seek *new* partners with such expertise (Lee and Berente, 2012). Second, with a prior partner, a qualitative change in the nature of the relationship could limit the usefulness of accumulated RSA in achieving integration outcomes. For example, aids in integration (such as boundary objects) may need to be renegotiated across the different experts involved and new boundary spanners with credibility across the new functions identified. Thus, when U.S. automakers adopted Japanese supply management practices (e.g., JIT and Kanban) and outsourced complete subsystems, both manufacturers and suppliers had to learn how to manage this transformation to their partnership.

[2] Dyer (2000) shows that the average distance between Toyota's and its supplier plants is much less than the corresponding distance for GM and argues that such close physical proximity provides Toyota with an advantage in integrating supplier activities relative to GM, for it enables rich and fast communications.

[3] While it may appear that the challenges faced by a firm in managing a disaggregated supply chain in general is not different from that of managing a *globally* disaggregated supply chain, the differences lie primarily in the degree to which such integration is different.

DOI: 10.1111/j.2042-5805.2012.01050.x

Modularity and integration

Another important approach to integrating supplier knowledge is a reliance on modular product and organization architectures. Organizational architecture represents the division of labor between the firm and its suppliers and the integration mechanisms used to coordinate activities (Baldwin and Clark, 2000), whereas product architecture represents a product's deconstruction into subcomponents and their interactions (Ulrich and Eppinger, 2005). Research has shown that when a product's architecture and its underlying knowledge are modular, integrating knowledge from external sources is less difficult (Baldwin and Clark, 2000; Brusoni, Prencipe, and Pavitt, 2001).

Entirely modular product architectures are relatively rare; this is especially the case with complex NPD projects involving cutting-edge technologies, due to the significant uncertainty regarding the nature of interdependence between the subcomponents (Ethiraj and Levinthal, 2004). In such situations, product designers often learn about component interdependences via trial and experimentation (Garud and Munir, 2008). In new automotive design, for example, designers cannot predict *ex ante* how components will interact to generate system performance such as noise or vibration (Becker and Zirpoli, 2009), a factor that constrains the designer from realizing a modular organizational architecture. In such settings, firms may be better off using an *integral* rather than a *modular* perspective (Siggelkow and Levinthal, 2003). Thus, NPD efforts involving integral products and breakthrough innovations require significant cross-team integration across different components (Sosa, Eppinger and Rowles, 2004; Zirpoli and Becker, 2011). Since suppliers often hold critical knowledge about subsystem designs, effective buyer and supplier knowledge integration is critical for breakthrough NPD projects.

In sum, NPD programs involving cutting-edge technologies that are distributed across *both* geographic and firm boundaries present unique integration challenges. As shown in Table 1, integration tools designed to manage such programs are limited. Co-location can be prohibitively expensive and technological uncertainty precludes modularity as an effective integration strategy. The need for specialized knowledge may require firms to work with partners who have no prior RSA, while changes to the program task requirements can make RSA from prior projects less effective. Finally, the unique integration tools available to an MNE are not available across buyers and suppliers. This suggests a research gap in our understanding of how firms effectively integrate activities in *globally disaggregated* complex NPD projects, a gap this article attempts to address.

METHODS

Approach and context

Our approach represents a combination of theory generation (Eisenhardt, 1989) and theory elaboration (Lee, 1999). We drew upon the emerging findings to elaborate and sharpen assertions made in these literatures. To guide the inquiry, we employed a conceptual framework consisting of a broadly defined

Table 1. Integration tools available in globally disaggregated NPD projects

Integration tools	Available within firm boundaries	Available across firm boundaries	Available in a globally disaggregated NPD program?
Authority	Yes	No	No
Normative integration	Yes	No	No
Relationship-specific assets	Yes	Yes	Only with partners with prior relationships*
Social integration	Yes	Yes	Only with partners with prior relationships
Modular architectures	Yes	Yes	Difficult to achieve in an NPD program that uses cutting-edge technology and a new approach, regardless of whether the activities are organized within or across firms.

*Relationship-specific assets (RSA) include things such as shared knowledge of decision-making procedures, development of a common language, and using shared routines and processes (Dyer and Singh, 1998). The purpose of normative integration is essentially to develop these same integration tools across subsidiaries of an MNE (Ghoshal and Nohria, 1989).

DOI: 10.1111/j.2042-5805.2012.01050.x

research question (provided in the introduction) and some potentially important constructs (e.g., modularity, co-location, RSA) from the extant literature.

Choice of Boeing and 787 program

Our choice of Boeing was driven by theoretical and pragmatic reasons. On the theoretical front, we focused on a program that represents a globally distributed NPD effort involving cutting-edge technologies where integration between the assembler and suppliers is crucial to program success. Additionally, the program was subject to a number of delays, chiefly attributed to integration issues between Boeing and its partners. Understanding the causes for these delays and the subsequent actions and outcomes provides a unique quasi-experimental setting to observe the development of integration capabilities in the context of a global NPD project.[4] More pragmatically, the access to significant personnel involved in the program provided a unique opportunity to observe the development of a complex product and its impact on Boeing's attempt at global integration.

The use of Boeing's 787 program represents a single case, but it was chosen deliberately due to the insights it could offer. Boeing's introduction of the 787, the real-time setting for the study, represents a revelatory case (Yin, 1994) and, as such, represents an important setting in which to study the research questions of interest. To industry observers, the Boeing 787 airplane represents a breakthrough product because 'with this airplane, Boeing has radically altered—indeed revolutionized—its approach to designing, building, and financing new products. Its role is that of 'systems integrator,' coordinating the design and development efforts of a group of largely non-U.S. partners' (Newhouse, 2007: 27).

The chosen time frame

Since the factors influencing the development of organizational capabilities and organizational design often include path dependencies that are cumulative and historically conditioned (Garud and Kotha, 1994; Langlois, 1988), a research design that generalizes uniqueness needs to be longitudinal. We selected 1996 as the starting point for analysis, since this was the year when Phil Condit unveiled Boeing's Vision 2016, the document setting forth the company's strategy for the next 20 years. Our end point was September 2011, the month that Boeing delivered the first aircraft for commercial use.

Data sources

We employed data from three sources: (1) interviews with Boeing senior executives, its suppliers, and industry experts; (2) press releases, internal Boeing publications, and other information available from public sources; and (3) e-mails and phone calls with executives to fill in gaps.

Interview data

Our primary sources were interviews conducted with multiple respondents within Boeing and its suppliers. We began the study with one of the authors conducting a four-hour interview with Phil Condit, former Boeing CEO, on whose watch the 787 was conceptualized and launched. This was followed by two separate interviews with Mike Bair, the first 787 program manager. We interviewed others, including the vice presidents in charge of supply chain management and quality; the director responsible for marketing and sales; and the airplane's interior design team; and other senior executives from units across the company. We also specifically interviewed three separate managers responsible for the Production Integration Center, one of the important tools Boeing employed to get greater control of its production system (described in detail later), to access *non-confidential* information about how this center functioned.

On two different occasions, we spoke to one of the directors in charge of the Vought factory in Charleston, South Carolina (one of Boeing's major suppliers, prior to the acquisition of this factory by Boeing). We did follow-up phone calls and e-mails to fill in the gaps after Boeing's acquisition of the Vought factory. Over a four-year period, we interviewed more than 20 senior executives directly related to the program. All interviews were recorded and professionally transcribed verbatim. Each interview lasted 1.5 hours on average and resulted in transcripts averaging 30-plus pages.

All interviews consisted of open- and close-ended questions. The closed-end part asked the senior manager to provide background information on the

[4] For this study, we specifically concentrate on the integration issues between Boeing and its six major structural partners: three Japanese firms, Mitsubishi, Fuji and Kawasaki; an Italian firm, Alenia Aermacchi; and two U.S. firms, Vought Aircraft Industries and Spirit Aerosystems.

DOI: 10.1111/j.2042-5805.2012.01050.x

program so we could supplement publicly available information with information directly gleaned from executives within Boeing. The open-ended part focused on non-confidential information unreported in the public media and Boeing press releases. Where appropriate and when relevant, we solicited information on managerial intentions and interpretation of how the program was conceptualized, structured, and unfolded over time. We used both nondirective and directive questions at different points in the interview to ensure data accuracy while reducing the priming effects where informants feel the need to answer a question in a specific way (Bingham and Haleblian, 2012).[5]

Books, cases, trade reports, and newspaper articles

We supplemented interviews with secondary sources, including accounts provided by books (Newhouse, 1985, 2007; Norris *et al*., 2005), business cases (Kotha and Nolan, 2005; Esty and Kane, 2001), magazine and newspaper articles, investment and industry reports, and Boeing press releases. We also examined media reports, which often provide contextual information about industry dynamics and firm- and program-level actions and activities. Investment and industry reports (e.g., Reuters, Flight International) enabled us to validate emergent ideas regarding changes observed over time. Additionally, we examined more than 800 newspaper and magazine articles on the program. Such multiple sources allowed us to examine the data from many vantage points and triangulate interview data with publicly accessible data such as media reports, press releases, and industry reports (Yin, 1994).

Analysis

We first analyzed the data by building our own case history for the Dreamliner 787 program. This case history was circulated to Boeing executives and corrected for factual errors. Using the material collected, we documented the airplane's evolution chronologically and then systematically examined the 787 program as it unfolded over time. To enhance theoretical sensitivity, we also systematically compared integration tools used across different partners over time. We were sensitive to the characterization of major structural partners to categories identified from public sources such as the extent of co-location and prior relationships with the Boeing program. Typical of qualitative research (Brown and Eisenhardt, 1997), we checked the validity of our insights with colleagues and senior executives. This iterative process resulted in multiple revisions and refinements. In the sections that follow, we discuss our detailed understanding of how the 787's organizational architecture and Boeing's integration capabilities evolved over the time period being studied.

[5] The information presented here includes only publicly disclosed details and contains no confidential information about the program.

THE BOEING 787 PROGRAM: A GLOBALLY DISTRIBUTED DESIGN AND PRODUCTION SYSTEM

Background and antecedents

In 1996, Phil Condit, the newly appointed Boeing CEO, unveiled a vision for the company. Dubbed the *Boeing 2016 Vision*, it presented the company manifesto: 'People working together as a global enterprise for aerospace leadership' (The Boeing Company, press release, 1998). In addition to becoming a global enterprise, Condit identified three major competencies that Boeing would leverage, *large-scale systems integration* being one. To industry observers, this meant Boeing wanted to transform its identity from a wrench-turning manufacturer into a master planner, marketer, and snap-together assembler of high tech airplanes (Newhouse, 2007).

Four years later, after two false starts, Boeing announced the 787 airplane (The Boeing Company, press release, 2002), a super-efficient plane that could fly as fast as today's fastest commercial airplanes, a major breakthrough for the aviation industry (Kotha and Nolan, 2005). A few years prior, in 2000, Airbus announced the commercial launch of the A380 super-jumbo, and by 2003 Airbus succeeded Boeing as the world's largest builder of commercial airplanes for the first time (Taylor, 2003). As a result, industry observers questioned Boeing's commitment to the commercial aviation industry as well as its ability to compete effectively against Airbus (cf. MacPherson and Pritchard, 2003). Given such concerns, the flawless execution of the 787 program was a competitive necessity for Boeing.

Organization architecture of the 787 program

Boeing decided to build the 787 airplane using titanium and graphite (Norris *et al*., 2005) making it the

DOI: 10.1111/j.2042-5805.2012.01050.x

world's first commercial aircraft built with composite materials, a decision that would have profound implications for the design and manufacture of the aircraft. The design called for decomposing the airplane's fuselage into major structural sections that could be built independently and mated together at the final assembly factory.

The global partnership model

Boeing decided this innovative product design was better suited to a *global partnership model* than earlier airplanes; now a global team of risk-sharing partners would help finance, develop, and market the airplane and Boeing, as the lead integrator, paid partners only after the airplanes were delivered to customers (*Seattle Times*, 2003). Boeing reasoned that risk-sharing partners would have an incentive to complete the work efficiently and help sell the airplane in their respective markets.

Transformation of supplier relationships

The 787 program represented an entirely new way of working with partners. In the past, Boeing had worked with its partners in a mode called *build to print* where engineers developed the design and detailed drawings (often hundreds of pages) for every part of the plane and then contracted with partners to build the parts to exact specifications. In the 787 program, Boeing requested each partner to *build to performance*, where Boeing engineers provided specifications comprising tens of pages with performance metrics that the parts needed to meet (Kotha and Nolan, 2005). Innovation, detailed drawings, and tooling would become the direct responsibility of the partners. Bair, the first 787 program leader, elaborates:

> 'What we had done (was take) the way that we have historically dealt with system suppliers and moved that into the airframe of the airplane. So rather than us doing all the engineering on the airframe and having suppliers do build-to-print, we put a fair amount of airplane design detail into the supply base. *The fundamental premise there is that you want to have the 'design and build' aspects aligned because to think that you could optimize for efficient production in someone else's factory, we have proven over and over again, is not the right answer. The suppliers know their factory and their capabilities*. They need to know this is going to work in order to make the subtle design decisions that they make in order to ensure that they optimize the production of the airplane.' (Mike Bair, pers. comm., 2008)

Figure 1, Boeing's template for implementing its global partnership strategy, illustrates how the airplane's major sections would be decomposed and built by partner firms. In all, 15 Tier 1 partners formed Boeing's new global network, with six taking on the responsibility for large structural sections (*Seattle Times*, 2003).

Bair noted that access to IP, as well as the need to reduce market risk, drove Boeing's supplier selection strategy:

> '[We looked] outside of the United States for partners. *The thing that we were after was intellectual capital*. We cast a net fairly wide in terms of getting the right, and the smartest, people in the world to help design this airplane. For example, the Italians, who were building part of the body and the horizontal tail, had some unique IP that we didn't have. The Japanese have brought us certain measured discipline. It is sort of foreign—certainly foreign to the United States and really foreign to the Italians. We really have gotten the best of the best in terms of getting these kinds of benefits.' (Mike Bair, pers. comm., 2008)

Another new element in this approach was the requirement that suppliers assemble subcomponents or *stuff* the modules before these were shipped to Boeing for final assembly. In previous programs, Boeing had assumed these tasks. Condit clarified the approach:

> 'It isn't that a lot of things are 'totally' new. Often it is simply that we haven't done it exactly this way in the past. What is 'new' is we are going to have a global partner 'stuff' the fuselage components, and we are going to snap it together with the central wing mount in an extraordinarily short time period.' (Phil Condit, pers. comm., 2008)

In other words, the 787 would be decomposed into completed *integrated assemblies*, or work packages, to be built around the globe and then transported to a Boeing final assembly plant at Everett, Washington.

Boeing chose an air transportation system to speed up delivery of work packages to Everett. The expected delivery time for work packages would be a day, rather than as much as 30 days in other airplane programs. During final assembly, the large integrated assemblies would be snap-fitted together in three days. The approach minimized the slack

DOI: 10.1111/j.2042-5805.2012.01050.x

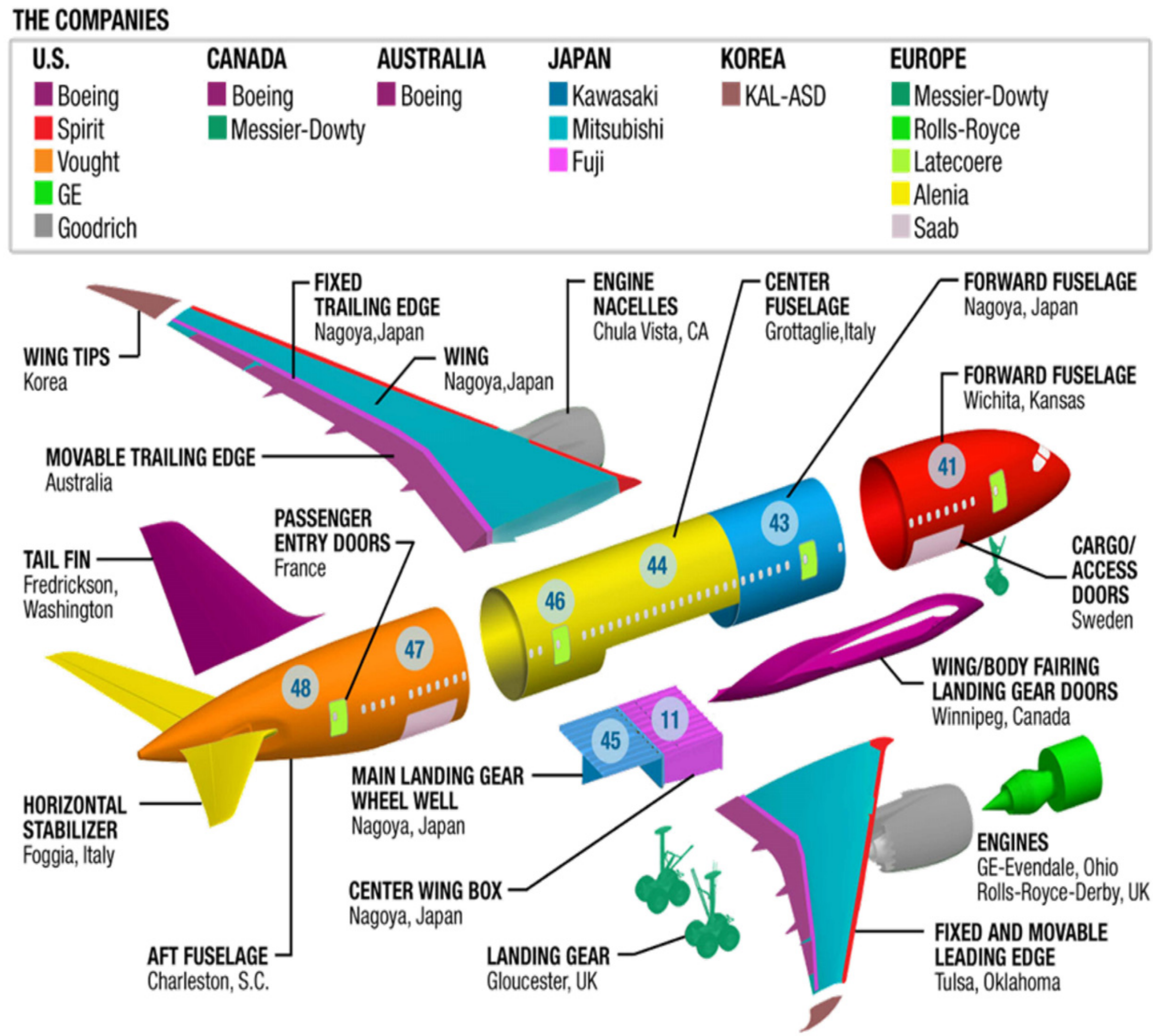

Figure 1. List of Boeing's global supplier partners for the 787 airplane
Source: Kotha and Nolan, 2005

available in the system and required a tight integration between Boeing and structural partners.

Organizational architecture

In the 787 program, Boeing had radically redesigned both the product and organizational architectures compared to programs such as the 767 or 777. The 787's organizational architecture is shown in Figure 2 (as finalized in 2004); the dotted line section represents Boeing's boundaries (the Everett factories), distinguishing it as a separate entity. The small *e* in the figure denotes the diminished engineering role of Boeing's engineering (relative to past programs), since partners handled many aspects of the airplane's design. The circled *E* in the various supplier boxes denotes the engineering/design work passed on to partners. The engineering and manufacturing interactions (shown by the arrows) at partner sites represent the 'design and build' alignment required for efficient production. Figures 1 and 2 together illustrate the 787's organizational architecture under which two factories—the Global Aeronautica (henceforth GA—a joint venture between Alenia and Vought) and Vought factories in Charleston—were central to the smooth functioning of the system because it was here that the partners preassembled major structural sections.

DOI: 10.1111/j.2042-5805.2012.01050.x

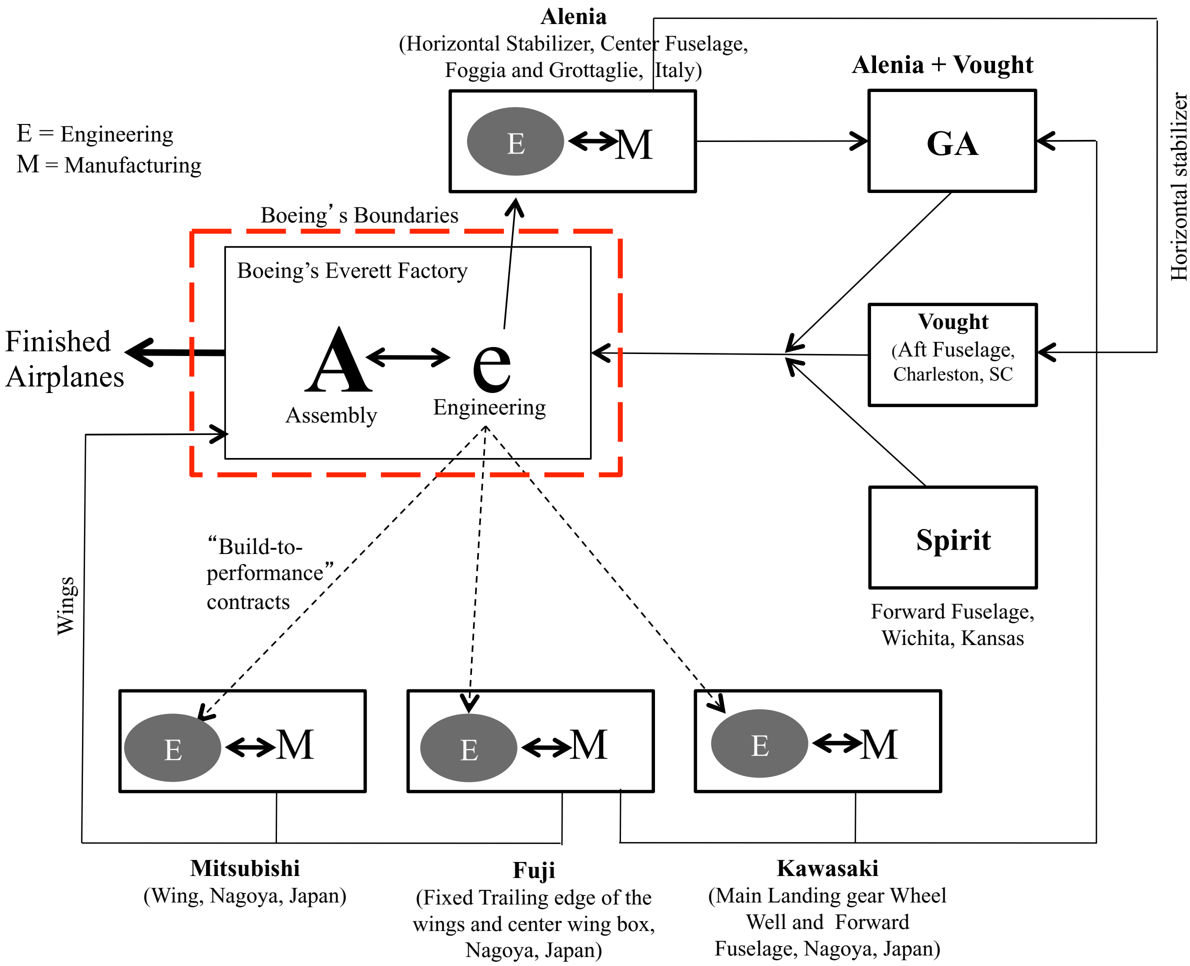

Figure 2. Simplified view of early architectural design for the 787 airplane, 2004
Source: Author's representation of Boeing's approach

In 2004, Boeing began taking customer orders and expected to deliver the airplane in four years. Customers eagerly signed on, making the 787 the fastest-selling airplane in commercial aviation history. However, events turned out differently than planned during implementation.

Delays to the 787 program: integration problems and attempts to fix them

Starting in September 2007, the program started running into embarrassing delays—delays that represented a serious setback for Boeing's intent of being a *large-scale systems integrator*. Table 2 provides a summary and reasons for the 787 delivery delays. The delays were attributed to Boeing's problems in implementing the global partnership model. According to *The Wall Street Journal* (Lunsford, 2008b: B1):

> 'Boeing extolled the business virtues of having suppliers from as far away as Japan and Italy build much of the fuel-efficient new jetliner, with Boeing performing final assembly . . . But the plan backfired when suppliers fell behind in getting their jobs done . . . [and] Boeing was forced to turn to its own union workforce to piece together the first few airplanes after they arrived at the company's factory in Everett with thousands of missing parts.'

Jim McNerney, Boeing's current CEO readily admitted Boeing's difficulty in executing its chosen strategy and noted:

> 'But we may have gone a little too far, too fast in a couple of areas. I expect we'll modify our approach somewhat on future programs—possibly drawing the lines differently in places with regard to what we ask our partners to do, but also sharpening our tools for

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Table 2. Major delays announced to the 787 program and stated reasons (2007–09)

Delay #	Delay announcements	Cumulative delays	Reasons for the delays as reported by Boeing and discussed in the media
1	September 2007	3 months	Problems are the result of unexpected shortages of fasteners and the inability of Spirit to deliver the forward fuselage module (see Section 41 in Figure 1). Spirit ascribed the delays to difficulties in completing the software code needed for flight control systems by Honeywell, a Tier 2 supplier to Spirit.
2	October 2007	6 months	Media reports and Boeing blamed the problems on Boeing's **supply chain network.** No details were specified.
3	January 2008	9 months	Boeing blames the delay on start-up challenges it faced in Boeing's factory and in factories of the extended global supply chain. The focus of blame is on **supply chain and capabilities** of the Boeing subsidiaries and its Tier 1 partners.
4	April 2008	1 year	Boeing blames the delays on problems with **carbon fiber technology** in the center wing box made by one of its **Japanese partners**. The media identified this partner as Kawasaki Heavy Industries (KHI). The wing-box was too light and needed strengthening. Although this was the primary responsibility of KHI, Boeing engineers worked on a patch to fix the early airplanes with this problem. Boeing blames **botched assemblies of the first fuselages** at the Charleston, Vought, and GA factories for most of the delays. Incomplete work transported from these factories to Boeing's plant at Everett played a large part in the issues faced by the final assembly line at the Everett factory. Vought, in turn, blamed Kawasaki Heavy Industries for sending incomplete work and noted that they (Vought) lacked authority to discipline this supplier.
5	December 2008	2 years	Delays were due to **improper work done by partners**. Boeing had to replace improperly installed fasteners in the early production airplanes. The media attributed the improper fastener installation to poorly written technical specifications that Boeing provided its partners as well as suppliers′ lack of experience with this kind of work (suppliers, in this case, were GA and Vought). Boeing is faced with a 58-day strike by the machinists' union at its final assemble plant at Everett. Machinists are unhappy with wage increases offered by Boeing and they are also **unhappy with Boeing's 'global partnership model**,' where 787 jobs were being outsourced.
6	June 23, 2009	2+ years	Delays are blamed on **structural flaws** resulting from mating the wings to the fuselage of the airplane. The flaws are blamed on engineering issues, but no mention of who is responsible for the flaws. Mitsubishi Heavy Industries, a Japanese partner, was responsible for the wings.

overseeing overall supply chain activities.' (The Boeing Company, press release, 2008)

This quote indicates that Boeing had limited integration capabilities and many of the partners lacked the required skills too. To fix the problems, McNerney directed that 'Boeing managers take a more aggressive role in sticking their noses into suppliers′ operations, including stationing Boeing employees in every major supplier's factory' (Lunsford, 2008a: B1). He named Pat Shanahan to head the program and reassigned Bair.

DOI: 10.1111/j.2042-5805.2012.01050.x

As Table 2 illustrates, the botched assembly of the first 787 fuselages at two factories in Charleston were responsible for the early delays. At Charleston, Vought Aircraft Industries managed one factory and GA managed the other. Incomplete work from here 'played a large part in the snafus that snarled the final assembly line in Everett that has delayed the 787's first flight by 14 months' (Gates, 2008: A1). In response, Elmer Doty, CEO of Vought, countered:

> 'Vought's role in the venture became problematic when the supply chain broke down and work that was to be completed by other major suppliers arrived in Charleston unfinished. . .The problem was Vought had no control over the procurement of those large pieces [from Kawasaki, a Tier 1 Japanese partner in the program]. Boeing, as the prime contractor was responsible for managing those major partners . . . To manage the traveled work efficiently, you need that responsibility . . . That is best done by the prime [contractor].' (Gates, 2008: A1)

Doty blamed Boeing's organizational architecture for the delays.

As Table 2 (Delay No. 1) indicates, Spirit, formerly Boeing Wichita, was also responsible for some of the early delays. This partner was responsible for the forward fuselage of the airplane, including the airplane's cockpit installation and Honeywell, a subcontractor, was responsible for the airplane's flight control systems (Lunsford, 2007).

Boeing managers took a series of steps to address the delays and get the 787 program back on schedule. Broadly, their efforts focused on three major approaches: (1) adding engineers and promoting collaboration through co-location; (2) redrawing the boundaries of the 787 program to bring the major fuselage assembly in-house; and (3) building the necessary tools to improve Boeing's strategic integration capabilities.

Adding engineers and promoting collaboration through co-location

Boeing reassigned engineers from its other divisions to the 787 program to take responsibility for the specific parts of the airplane such as electrical systems, structures, and computers (Michaels and Sanders, 2009). Importantly, Boeing engineers' role had gone from being passive observers to active participants. This new approach resulted from McNerney's directive that Boeing managers 'stick their noses into suppliers′ operations.' As Bair observes:

> 'Some of the things that we have learned [from the delays], and this is primarily around structural partners, we had assumed basically that all of the structural partners could do the exact sort of work statement. Bad assumption; some of them were really good at delivering the "whole package" and some of them had some deficiencies.' (Mike Bair, pers. comm., 2008.)

Boeing engineers began to collaborate more intensely with partner firms to resolve immediate issues and avoid future delays. Specifically, Boeing responded by throwing both money (about $2 billion in additional R&D expenses) and people at the problem. It dispatched 'dozens or hundreds of its own employees to attack problems at plants in Italy, Japan, and South Carolina' (Lunsford, 2007: A1). Boeing engineers and production workers were stationed in the factories of Tier 1 suppliers to share their expertise and facilitate integration. Much of the focus and attention was centered on *bottlenecks*—the GA and Vought factories where preassembly was done, as Shanahan publicly discussed.

> 'We′ve had people, whether its supervision helping them with incorporating [design] changes back in Charleston or whether its been folks helping them with their supply chain, that's been ongoing for a better part of the start up of the program [since 2006]. More recently, we just had a higher influx of people into Charleston because you compare the capability and capacity, the limitation is there, it's not at Spirit, it's not at MHI or KHI or FHI. That seems to have the biggest payoff.' (Ostrower, 2009)

In fact, production delays recovered rapidly at Spirit and Boeing managers attributed its quick turnaround to its former Boeing heritage and Spirit's familiarity with Boeing's tools and process (Gates, 2008). Figure 3 is a schematic representation of the changed organizational architecture, and the arrows between Boeing's engineering group and the suppliers' engineering groups represent a marked departure in approach compared with Figure 2.

Redrawing the boundaries

In March 2008, Boeing bought Vought's 50 percent stake in GA, forming a Boeing and Alenia joint venture. GA was the staging site where major fuselage sections from the Japanese and Italian partners were preassembled. Boeing attributed inefficiencies with GA for some of the delays.

In a major move a year later (August 2009), not pleased with the progress, Boeing bought Vought's

DOI: 10.1111/j.2042-5805.2012.01050.x

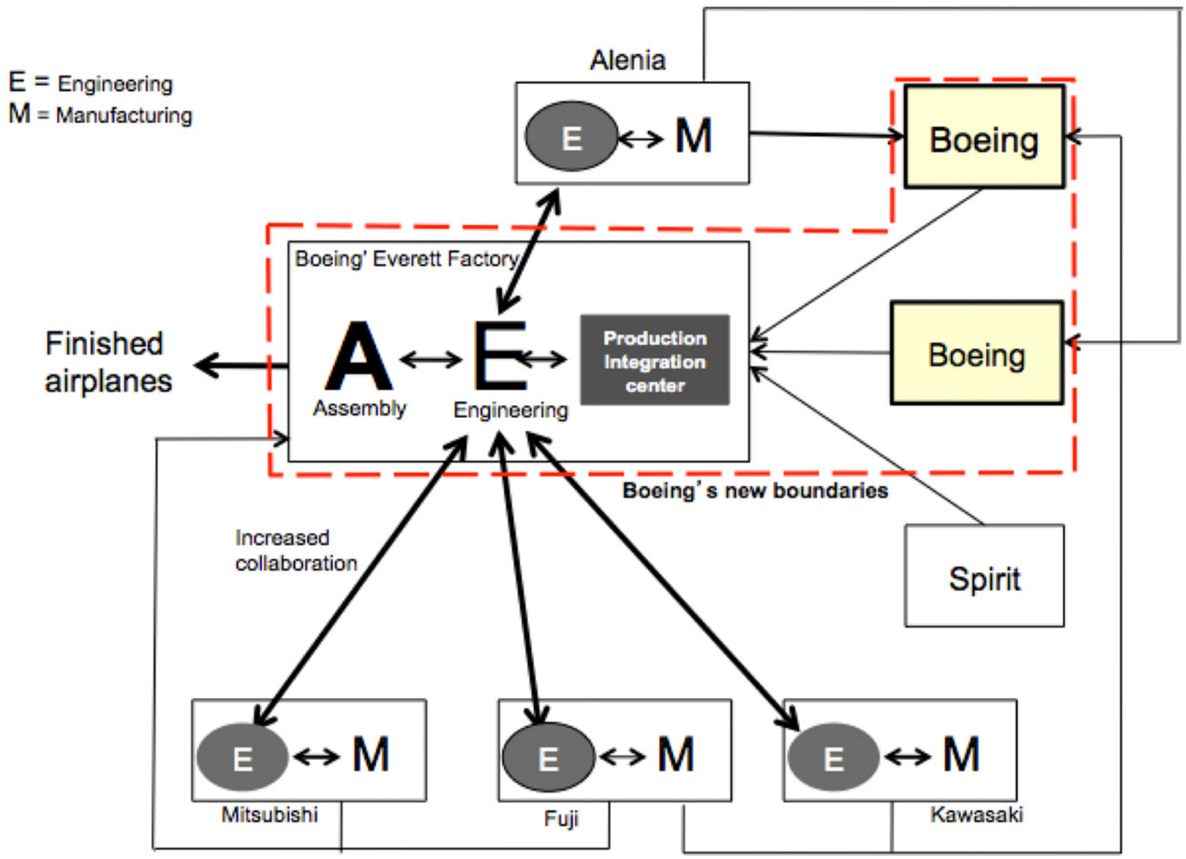

Figure 3. Simplified view of the changed architectural design for the 787 airplane, 2009
Source: Authors' representation of Boeing's approach

Charleston factory, relegating Vought to the role of a supplier of components and subsystems.[6] In December 2009, Boeing dissolved its joint venture with Alenia and took full control of the GA factory in Charleston. Thus, Boeing took over the entire preassembly activities at the Charleston location, a major move that addressed Doty's earlier comments that responsibilities needed to be aligned. To industry observers, this was not a surprise, as Scott Fancher, the next 787 program manager had publicly noted that this might happen:

> 'You know, you get into a situation where either some of the first tiers or their sub-tiers simply aren't able to perform: now there could be a lot of reasons for that, could be that they are in financial stress, could be that technically they′ve run into a situation they can't handle, or could be the complexity of the production of the product that they′ve designed is beyond their capability; so we tend to look at the root cause of the nonperformance and how can we help them succeed . . . Clearly as we go forward, we′ll look at some rebalancing of work scope as we sort through where work is most efficiently and cost effectively done, but by and large, the focus is on helping our supply chain succeed, not moving the work in a rapid fashion [without completing it].' (Ostrower, 2009)

Boeing reorganized Vought's factory and took responsibility for assembling the airplane's floor grid, which was previously outsourced to Israel Aircraft Industries; this supplier's role would now be limited to delivering components, which were then assembled into full sections by Boeing employees and installed into the fuselage at the Charleston plant. Similar changes were carried out throughout

[6] After taking charge of the 787 program, Pat Shanahan's first major move was to reassign a senior Boeing executive who was in charge of 787 production to oversee all the development activities at the Vought factory at Charleston.

DOI: 10.1111/j.2042-5805.2012.01050.x

the global supply network, to rationalize the production network and redefine areas of responsibility to match Boeing and supplier's capabilities.

Building tools and routines for integration

The new global partnership strategy dictated that instead of individual parts, *stuffed* modules or *work packages* would be assembled at Everett. In line with Boeing's blueprint for the 787, the factory was optimized for *snap-fitting* major completed sections. So when incomplete work packages began to arrive (Delay No. 3 in Table 2), the Everett factory was unable to assemble these subsections.

Boeing managers recognized that for the system to work effectively, greater oversight of the supply chain system was necessary, as McNerney had observed. Echoed Scott Carson, CEO of Boeing Commercial Airplanes, 'In addition to oversight [of the program], you need insight into what's actually going on in those [partner] factories . . . Had we had adequate insight, we could have helped our suppliers understand the challenges' [Lunsford, 2007: A1]. In other words, having insight or visibility would have enabled Boeing to predict, not just react to, supply chain contingencies (e.g., Delays No. 3, No. 4, No. 5, and No. 6). According to Ben Funston, one of Boeing's executives in supply management:

> 'On a legacy program you can pretty much walk out into the Everett factory and kind of get a feel for how production's going . . . The reason isn't because that's an all inside make, but basically because we ship in a bunch of small subassemblies and we integrate it all here . . . In the 787, by the time you get here to Everett, you're receiving a few sections of fuselage and wings and we integrate it here . . . So we needed a tool to give us *situational awareness* into the production system and the ability to have early issue detection and real-time problem resolution. If you find it here or even if you find it at the partner before he's getting ready to ship, it's too late.' (Creedy, 2010)

Creating visibility

To create situational awareness or visibility, the 787 team created the Production Integration Center (PIC) in December 2008. According to Bob Noble, vice president for 787's supply chain, the center's purpose was 'to provide situational awareness, early issue detection, and real-time problem resolution for the 787 Dreamliner production system' (Ostrower, 2009). The PIC is a 5,100-square-foot center that operates around the clock, with translators for 28 different languages (James, 2009).[7] The center was manned by multifunctional teams of experts who specialized in different functional areas pertaining to aircraft design, avionics, structures, technology, assembly, and logistics. The center also continuously monitored conditions around the world (ranging from natural disasters, such as tornados or earthquakes, to political situations like riots, to epidemics like the swine flu), all of which could potentially affect production and transportation of finished fuselage sections to Everett (James, 2009).

The PIC was designed as a centralized facility to help integrate the global product system. First, it helped coordinate problem solving by improving communication and facilitating collaboration among Boeing and partner engineers. For instance, if an engineer at one of the partner sites had an issue, he/she could contact the center to be connected with appropriate Boeing personnel who would help resolve it. Hence, Boeing could now respond to issues by helping suppliers' engineers communicate directly with their Boeing counterparts. Second, as the center's partner call volume increased, managers instituted routines to prioritize them (Creedy, 2010).[8] This provided greater focus and attention to issues that mattered in resolving delays.

Third, the center provided high-definition cameras at partner sites so engineers at partner sites could employ multimedia communications to diagnose and address problems. As Michaels and Sanders (2009: 7) observed,

> 'Suppliers as far afield as Australia, Italy, Japan and Russia could call in through translators and show Boeing engineers in the center close-up images of the their components using high-definition handheld video cameras . . . Immediate, multimedia communications have eliminated the problem of unclear e-mail exchanges between distant engineers who work on the opposite ends of the clock.'

[7] The PIC holds 27 workstations, each with three screens, and a huge (40- by 10-feet) video screen in the front of the room, with 24 separate screens that monitor news around the world, report on global weather patterns, provide real-time information on production issues with each supplier, highlight the health of 787-related computer servers, and display shipping schedules for the four giant Dreamlifters (converted 747s that transported 787 parts to Everett) (James, 2009).

[8] Funston, one of the senior executives, observes, 'If we came in and said this is an absolute line-stopper for the program, then everyone stops what they are doing at that site and realigns to that priority' (Creedy, 2010).

DOI: 10.1111/j.2042-5805.2012.01050.x

Table 3. Processes and routines developed at the PIC to foster integration

Types of processes instituted	Functional goal of the processes and routines	Learning that resulted from employing the processes
Integrating production A set of processes and routines developed to track production activities at Tier 1 partners.	Gain greater visibility into partners' activities. The emphasis was on problem diagnosis.	Generating visibility, Boeing is able to surface problems before they disrupt the schedule. Such visibility is currently limited to Tier 1 partners. Boeing could establish PIC-like facilities at other factories, which should enable it to gain visibility into Tier 2 suppliers.
Coordinating calls for assistance A set of routines to (1) manage and catalog incoming calls for assistance from Tier 1 partners, and (2) track and monitor calls.	Enable partners to contact Boeing for expertise to help problem diagnosis and resolution. The emphasis is on enabling 'knowledge' visibility for partners.	Using data on incoming calls, managers were better informed about partner challenges and resources they need to resolve problems.
	Created a sense of urgency on the part of PIC managers to resolve problems at partner sites.	High definition video cameras provided rich data on the artifact and the context needed to make decisions. Such rich communications made problem diagnosis and resolution more productive.
		If certain calls were not resolved within a given time period, they were escalated to senior managers for resolution.
Coordinating air transportation A set of routines to manage a Boeing fleet (modified 747s airplanes) to transport preassembled sections.	Assist with material flows among partners and between Charleston and Everett. The emphasis is on integrating the supply chain.	As the system achieved a modicum of stability, the center's primary responsibility shifted to managing the air transportation fleet to transport preassembled sections from partners to Boeing facilities.
Monitoring potential disasters A set of routines to monitor/assess events that could potentially disrupt the global supply chain.	Predict rather than react to potential disruptions. The focus is to ensure that supply chain linkages are maintained through alternate arrangements, if needed.	The system worked as designed. The PIC center keeps senior management and partners informed of disruptive situation when they happen.

Using such visual access to partner sites and rich information, Boeing developed a variety of proprietary routines to gain visibility and monitor the system.[9]

Lastly, the center took responsibility for transporting structural sections throughout the network and ensuring that they arrived at Everett on schedule. Boeing managers recognized that effectively managing the transportation of large fuselage sections was critical for system effectiveness. With this new air transportation system, Boeing minimized work in process inventory (and related carrying costs) by reducing the time it took to transport large fuselage sections for assembly at Everett. This approach was in line with Boeing's stated goal of becoming a lean manufacturer as described in Boeing's 2016 vision document. Table 3 details the routines the center developed to create visibility. Also the PIC is represented as an important addition as shown in Figure 3.

[9] For instance, managers created routines for recording and monitoring phone calls for assistance from partners, visually mapping and updating production status at partner factories in real time. They also developed simulation routines to understand system behavior when faced with major disruptions.

DOI: 10.1111/j.2042-5805.2012.01050.x

The evolution of the PIC

Over time, the type of calls and volume received changed, and the center's role evolved. Initially the incoming calls focused on resolving aircraft design issues between engineers at partners and Boeing engineers, and this was then followed by incoming calls focusing on production-related issues. To address them, first the center was initially staffed with multidisciplinary teams of engineers representing major aircraft systems. Then it was organized to support each Tier 1 supplier to handle production-related issues (i.e., the groups within the PIC who worked mostly with a specific supplier and handled integration problems). As the aircraft design and production-related issues were slowly resolved, the center took requests for the rapid delivery of critical parts needed at partner factories in addition to scheduled transportation of preassembled sections. It was then reorganized to address final assembly issues at Everett.

The center served as the *mission control* for the 787's global supply chain using its proprietary routines. With time, Boeing has reduced the number of its engineers co-located at partner sites and the resources allocated to the PIC. Industry experts concur that the center was pivotal in stabilizing the 787's supply chain as measured by declining travelled work (Ostrower, 2009). Travelled work represents work that should have been completed by the supplier but, given the schedule requirements, was not accomplished there but nevertheless was shipped to Everett for Boeing workers to complete. After almost three years of delay, Boeing delivered a 787 airplane to launch customer All Nippon Airways (ANA) in September 2011.

DISCUSSION

Our intent was to understand how firms integrate activities in *globally disaggregated* complex NPD projects. Our analysis suggests that the lead integrator, Boeing, faced challenges pertaining to three distinct components of integration. Boeing recognized they needed two types of visibility to address these integration challenges and invested in the necessary tools to effectively increase visibility.

Components of integration

Boeing faced integration challenges relating to: (1) design integration; (2) production integration; and (3) supply chain integration.

Design integration

This pertains to how Boeing divided and distributed major airplane design-related tasks to partners, based on an initial assessment of partner capabilities and expected coordination costs. Boeing managers felt that the 787 airplane program merited a global partnership model, which was broadly in concordance with its intent to transform its identity to become a *global large-scale systems integrator*. Also, Boeing was interested in mitigating financial and marketing risk and securing IP rights for composite technology.[10]

One criterion Boeing employed to allocate tasks involved partners' underlying competence to implement a complex program: three major Japanese firms had worked with Boeing designing wings for the 777 and 767 airplanes, programs dating back to the 1980s, which made them ideal partners. Boeing's relationship with Alenia, the Italian manufacturer, also dated back to the 1980s; moreover, Alenia possessed expertise in specialized composites that Boeing needed (Mike Bair, pers. comm., 2008).

The 787 program differed in one important respect. In the past, Boeing had provided detailed specifications, but for this program it chose to supply only broad design parameters; partners had to use their own expertise to design and build major structural sections of the airplane. Boeing assumed that the chosen partners would have the requisite competencies to do design and integration work and build preassembled sections, but this assumption would prove invalid. Bair conceded, 'We had assumed basically that all of the structural partners could do the exact sort of work statement. [This was a] bad assumption' (Mike Bair, pers. comm., 2008). Thus, when some partners were unable to perform as expected, the program faced delays.[11]

[10] While task assignment (who does what) represents a high-level decision choice (e.g., wings are to be made by Mitsubishi) and is relatively simple to envision, it is generally harder to achieve at the activity level (e.g., should Mitsubishi or Fuji be responsible for designing how to join the wings to the center wing box?).

[11] *Ex ante*, it appears that the tasks performed by Vought and Alenia were more complex and subject to greater uncertainty than those performed by the Japanese partners. Thus, while the Japanese were largely responsible for delivering subcomponents, along with building parts of the composite fuselage, Vought and Alenia, were responsible for *stuffing* them, a task that Boeing's partners had never done before. Also, as Bair notes, the Japanese partners were admired for their disciplined approach, something that Boeing's U.S. and Italian partners seemed to lack.

DOI: 10.1111/j.2042-5805.2012.01050.x

Another criterion for allocating tasks was designing a system that reduced coordination costs. As the program unfolded, it became clear that GA and Vought factories were vulnerable to misalignment issues caused by organizational architecture (see Delays No. 4, 5, and 6). While they integrated major subsystems from Tier 1 partners, they lacked the disciplinary authority when incomplete subassemblies arrived in Charleston. This was essentially the complaint that Doty, Vought's CEO, had made when he noted it was Boeing, not Vought, who was responsible for managing other Tier 1 partners.

Our analysis suggests that design integration includes both short- and long-term components. In the short term, the airplane has to be delivered to waiting customers and decisions regarding the realignment of tasks allocated to partners followed that imperative. Faced with mounting delays, Boeing bought out Vought's stake in GA. Prior to the acquisition, Boeing co-located numerous engineers at Vought and Alenia to support them. As co-located managers assessed partner capabilities, they came to understand the interdependencies between partners. In the longer term, however, as efficiency considerations become more salient and the production system stabilizes, Boeing could consider externalizing its factories at Charleston. Boeing's Vision 2016 mission statement called for precisely such a transformation.

Although the six Tier 1 risk-sharing structural partners might have worked together to achieve better integration, in reality Boeing, as the central actor, intervened to make changes. Using its bargaining power, the company changed the division of labor to achieve better task allocation, reflecting studies of large-scale integration regarding the final assembler's central role in reconfiguring complex systems (cf. Argyres, 1999). Given the uncertainty of the nature of interdependence and the lack of precise information about partners' abilities, it is unclear whether Boeing could have achieved better design integration *ex ante*. Boeing has had relationships averaging 30 years with its six structural partners, which suggests that when qualitative changes are introduced into buyer-partner relationships (in this case, moving from *build-to-print* to *build-to-performance* model), *previous stocks of RSA may not be sufficient to make task assignment decisions of importance*.

Production integration

This integration pertains to how production-related tasks, including product design and manufacturing, are coordinated across partners and the final assembler. As Bair noted earlier, Boeing wanted each partner to design and manufacture subassemblies in order to align the *design and build* aspects at partner factories (i.e., partners and not Boeing were better positioned to optimize their factories for efficient production). Boeing's logic was to encourage a *thick interface* between design and build at partner factories instead of having them rely on Boeing as in previous programs (see Figure 2). However, in practice, the partners not only had to optimize their own factories, but also had to integrate their efforts with the lead integrator and other partners. Boeing had generated this skill in past programs, but their partners had not, since in the old build-to-print regime, suppliers worked mostly from codified knowledge Boeing shared with them. McNerney recognized this when he directed Boeing to 'poke their nose into supplier operations,' a message that was contrary to the initial program design approach. Importantly, the 787 team recognized that it needed a tool that would give them insight and visibility into partner facilities, as Scott Carson, the CEO of Boeing Commercial, had observed.

Achieving production integration required a number of changes. First, Boeing added more engineers and machinists, who then became active participants and collaborators instead of passive observers (contrast Boeing's role in Figure 3 versus in Figure 2). Second, hundreds of design and production engineers were co-located at partner factories, bolstering partner expertise, though it appears that the improvement in production integration came from their knowledge of Boeing's processes and ability to highlight partner deficiencies. These engineers are akin to *boundary spanners* (to use the terminology of Mudambi, 2011) who are recognized and credible to both Boeing engineers as well as partner engineers. They play a critical role in knowledge transfer across boundaries within a MNC firm and often across firms.

Third, managers created a unique IT-enabled centralized integration center (i.e., PIC) as described in detail earlier. This center was staffed with multifunctional teams and they instituted processes and routines for prioritizing and attending to calls so that requests for help from partners were dealt with in a timely manner. Such processes and routines are akin to what (Carlile, 2002) has described as *boundary objects* that are critical for knowledge transfer across boundaries. Boundary objects represent 'a means of representing, learning about, and transforming

DOI: 10.1111/j.2042-5805.2012.01050.x

knowledge to resolve the consequences that exist at a given boundary' (Carlile, 2002: 1526). They instituted routines that created a sense of urgency on the part of Boeing personnel to respond to requests by tracking and monitoring calls, accessing senior managers if needed. The center also included tools that established the necessary *contextual common ground* (Srikanth and Puranam, 2011) needed to resolve issues such as the use of translators and video cameras.[12] Overall, these routines enhanced joint problem solving between Boeing and its structural partners by increasing visibility.

Supply chain integration

Consistent with Boeing's relations with its structural partners, we characterize the supply chain as the purchasing operations and relationships between a firm and its first tier suppliers including buyer-seller alliances and partnerships (Cavinato, 1992; Blocher, Lackey, and Mabert, 1993). Effective supply chain integration is critical for network effectiveness and encompasses the integration of information flows, physical flows, and financial flows between a firm and its supply chain partners (Rai, Patnayakuni, and Seth, 2006). By design, Boeing chose to air transport preassembled sections removing slack in the system, which made supply chain integration a priority for the airplane's production.[13]

Supply chain integration challenges loomed large during program implementation (see Delays No. 3 and 4 in Table 2). To transport preassembled sections, processes and routines were instituted at the centralized integration center. One set was aimed at scheduling the airplanes Boeing used to transport sections to the preassembly factories in Charleston, and between South Carolina and Everett. Another set tracked potentially disruptive events (natural disasters such as earthquakes) so that appropriate actions could minimize their impact on material flows throughout the 787 network. These routines also enabled Boeing to monitor the work-in-progress at the partner factories enabling it to *predict* potential delays and address them in order to maintain the schedule. While in theory Boeing could have outsourced transportation of large fuselage sections, given the specialized nature of these assets (the ability to design and modify 747 jumbo jets), Boeing decided to do this in-house.

Visibility mechanisms for integration

As the 787 program unfolded, Boeing managers recognized that they needed two types of visibility to address the integration challenges they faced. On the one hand, partners needed access to Boeing's and other partners' expertise so that appropriate knowledge could be obtained for diagnosing and resolving problems. On the other hand, Boeing needed awareness of partner activities throughout the network to fully comprehend the issues confronting them.

We term the first type of visibility *knowledge* visibility and the second *activity* visibility. Activity visibility provides the contextual and tacit information necessary to solve problems and is helpful in monitoring partner activities in real time throughout the entire network. Knowledge visibility makes visible the locus of expertise that is available throughout the network. Without such visibility, partners find it difficult to locate the expertise needed to address issues confronting them in a timely fashion. Activity visibility and knowledge visibility, as discussed here, are independent constructs although they often coexist in practice.

To carry out effective design integration, the lead integrator needs to better understand the nature of interdependence, assess partner competence, and reassign tasks as issues arise. Both activity visibility and knowledge visibility help promote such an understanding and, in the process, enable better design integration. In production integration, the nature of the integration effort shifts toward addressing issues that often arise at the nexus of product design and manufacturing. Knowledge visibility helps access the expertise required from the network to solve such issues. Activity visibility promotes building contextual common ground between the partner and lead integrator (the one with the expertise) and helps the engineers better understand the tacit components involved in finding

[12] The need for context-specific knowledge to coordinate across locations is referred as contextual knowledge, contextual awareness, or contextual common ground in the academic literature (Kraut *et al*., 2002; Olson *et al*., 2002). But Boeing managers internally refer to such knowledge as situational awareness.

[13] With time and greater stability in the production network, supply chain integration has increased in importance. Such integration is likely to become even more complex as Boeing ramps up production from the current production of two planes per month to a planned rate of 10 a month. Boeing opened a final assembly plant at its Charleston location next to the two factories it acquired from Vought and Alenia, modeled after its final assembly plant in Everett.

DOI: 10.1111/j.2042-5805.2012.01050.x

a solution.[14] Therefore, both activity and knowledge visibility play an important role in production integration. With regard to supply chain integration, the onus is on predicting likely disruptions and addressing them before they ripple across the network. Activity visibility enables monitoring partner factories to predict potential disruptions that can occur. Knowledge visibility, in this context, can help engineers find ways to ensure that schedules are synchronized and deliveries are prioritized so that disruptions in the supply chain are minimized. In summary, both activity visibility and knowledge visibility are important in achieving all the three components of integration.

Tools for integration

Boeing used a combination of traditional and novel tools to enable visibility of both kinds. These included: co-location, the PIC, and vertical integration.

Co-location

In general, co-location provides both high levels of contextual common ground and unconstrained opportunities for rich face-to-face interactions, thus enabling a lead integrator to achieve activity visibility. Through such visibility, the lead integrator can assess suppliers' competence, understand the nature of interdependence, and engage in joint problem solving. In other words, with activity visibility, the lead integrator could redesign/reassign tasks to facilitate better design integration. The quality of activity visibility that co-location permits makes it an important tool for achieving production integration (see Table 4 for details).

In our context, despite its initial organizational architecture for the 787 program, Boeing discovered that some co-location was unavoidable, especially during the early phases. Co-locating Boeing personnel at partner factories aided integration by providing Boeing the ability to see partner activity and assist them in accessing expertise at Boeing. In other words, co-located Boeing personnel were able to deeply understand the issues partners faced in their respective factories and knew whom to contact at Boeing Everett to help address such issues. Co-locating personnel also provided Boeing the ability to assess partner competence and willingness to adapt and learn, providing a *partner monitoring* mechanism.

Centralized integration support center

Boeing found one reason for program delays was that some of its partners were unable to complete the task assigned them in a timely manner, frequently because of cascading interdependence between the partners. The partners needed the knowledge regarding whom to contact at Boeing to help fix issues and Boeing, for its part, needed to know which of the partners needed assistance. Additionally, Boeing needed a mechanism to access the tacit knowledge regarding the partner's context to better appreciate and help partners solve problems.[15] In other words, although Boeing, as the prime contractor, was ideally suited to facilitate *inter-partner* integration, it was unable to do so without the necessary activity visibility and knowledge visibility.

Through the centralized center, Boeing was able to gain information about partner activities and the situational context and the partners, in turn, had a way to access Boeing's expertise. The center promoted activity visibility through the use of high-definition cameras and artifact-based communications. Based on the requests for assistance from distributed partners, the lead integrator mobilized and directed resources and expertise to solve problems at partner factories, achieving production integration. In fact, the center centralized and prioritized communications and routed problems to potential solvers across the network. In other words, the center (and the specific processes and routines that underlie it) promoted both activity and knowledge visibility that, in turn, enabled design (i.e., task reassignment) and production integration. The activity visibility also gave Boeing access to information needed for better supply chain integration. Some examples of how both activity and knowledge visibility generated

[14] Suppose Supplier X has Problem P. Supplier X needs to search to find out who can help solve this problem. Knowledge visibility allows Supplier X to find out that Engineer Y is the lead integrator or another partner can solve this problem. In order to solve this problem, Y needs activity visibility because X cannot articulate all the tacit contextual information that is necessary to solve the problem.

[15] Both these issues were new to the 'build to performance' regime instituted with the 787 program. Boeing had initially assumed that it was best to resolve integration issues by tightly coupling design and manufacturing at partner sites. However, this approach failed to address the need for integration between partners and Boeing and among partners when program implementation started.

DOI: 10.1111/j.2042-5805.2012.01050.x

Table 4. Integration components and integration tools in the 787 program

Integration Tools	*INTEGRATION COMPONENTS*		
	DESIGN INTEGRATION	PRODUCTION INTEGRATION	SUPPLY CHAIN INTEGRATION
VERTICAL INTEGRATION	Provides the authority needed to align tasks and responsibilities.	Can enforce actions unilaterally to increase visibility of activities at geographically distributed facilities within the firm.	Can enforce actions to increase visibility of actions to predict issues. Can modify/change scheduling priorities at company-owned facilities for smoother supply chain operations.
CO-LOCATION	Promotes visibility of activities that allows for evaluating interdependences between actors and the lead integrator. Promotes knowledge visibility to understand competencies of the supplier.	Promotes visibility of activities, which helps the prime integrator to better understand partner challenges in carrying out the distributed tasks. Co-located personnel can act to promote knowledge visibility by helping partners find the required expertise at Boeing to resolve problems.	Not used in our setting.
The PIC			
Artifact-based communication using high-definition cameras	Allows for visibility of activities using rich data, but likely to be less effective when cutting-edge technology programs are involved.	Visibility of activities allows for effective problem diagnosis and resolution across geographies, and cuts days out of the problem-solving loop.	Could communicate the severity of damage (using rich data) at partner facilities in the wake of a natural disaster or help describe production problems (using rich data) that could impact the schedule.
Resource (expertise) mobilization	Not applicable.	Enables the integrator to direct resources and expertise to solve problems at partner sites. Partners gain visibility to knowledge at Boeing.	Enables integrator to direct resources available at Boeing to help the supplier manage activities better to resolve potential ramp-up problems.
Centralization, prioritizing activity, and monitoring to follow-up for resolution	Not applicable.	Ensures more important problems are resolved before smaller problems are tackled. Creates a sense of urgency at Boeing to respond to requests for assistance. Also, top management can be informed or looped in, if needed. Highlights integration needs (such as approvals for design changes in our setting).	Ensures that schedules are synchronized and deliveries are prioritized to ensure that disruptions are minimized. Centralized tracking and monitoring enables effectively closing the loop on supply chain issues.

DOI: 10.1111/j.2042-5805.2012.01050.x

by the center were important in achieving design, production and supply chain integration are illustrated in Table 4.

Vertical integration

Faced with short-term pressures and the inability of the Vought and GA factories to resolve issues rapidly, Boeing acquired these facilities, using its authority as the prime contractor for bargaining clout. Despite having significant prior relationships with Boeing and being risk-sharing partners, these partners were reluctant to reorganize their factories to generate the required action visibility. Some of the partners also lacked the authority to direct the actions of other Tier 1 partners while still being responsible for integrating their work. The traditional role of vertical integration is that activities in subunits could be reorganized by recourse to fiat, which is how Boeing gained the authority to reorganize the factories in South Carolina. Boeing then opened them up for closer scrutiny, thus improving activity visibility, which facilitated all three integration components.

Figure 4, in a simplified framework, highlights the interrelationship among the three components of integration, the mechanisms, and the tools discussed earlier. Vertical integration enables integration of all three components primarily through action visibility. Both co-location and developing a centralized center enable integration of all components via both activity visibility and knowledge visibility. However, as illustrated in the different weights of interconnections, the knowledge visibility created by a centralized center (i.e., the PIC) appears superior to that solely dependent on co-locating engineering personnel at partner facilities, because knowledge visibility created by a co-located engineer is limited by his/her ties in the network. However, a centralized system can help a partner gain access to experts throughout the network, giving the center the ability to rapidly match knowledge sources with where they are required. However, activity visibility generated by a centralized center is not as detailed as that generated by co-locating personnel, since being immersed in the context allows for much richer interactions than using tools such as video cameras. As shown in Table 4, though knowledge visibility generated by co-location is also useful for production and supply chain integration, co-location's impact is less important for these in our setting, primarily because the centralized center took over many of these functions.

CONTRIBUTIONS, LIMITATIONS, AND CONCLUSIONS

We began with the premise that NPD programs that involve cutting-edge technologies distributed across

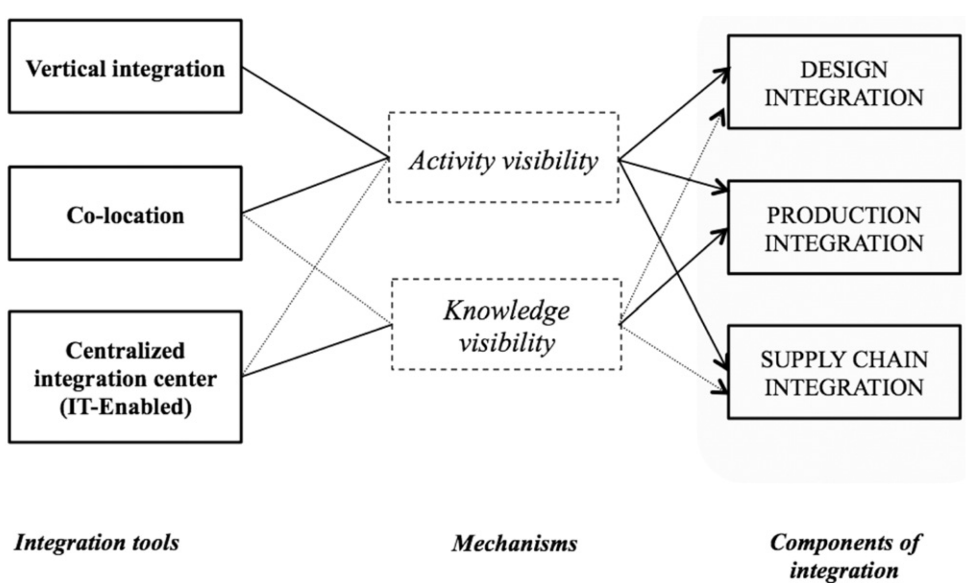

Figure 4. A proposed framework for achieving global integration

DOI: 10.1111/j.2042-5805.2012.01050.x

both geographic and firm boundaries presented unique integration challenges. In this case, technological uncertainty precluded modularity, and co-location of assembler and supplier engineers (as has been done in the past) is expensive. Prior work on buyer-supplier relationships has been silent on how to manage the impact of geographic dispersion, except to point out that greater dispersion may result in poor integration outcomes (Dyer, 2000). The extant international business research has emphasized how the level of unified authority characterizes the integration issues within MNEs (Mudambi and Navarra, 2004). However, such authority is generally absent in buyer-supplier relationships. It is from this context that this article makes novel contributions.

First, to the best of our knowledge, this is the first study that provides a holistic understanding of what constitutes achieving integration from the context of a complex NPD program carried out across geographic and firm boundaries. We found three distinct components of integration capabilities. Prior studies of complex NPD programs primarily highlighted 'production integration' challenges and neglected the design and supply chain integration issues faced by firms using a globally distributed partnership model. Our finding suggests that as firms grapple with production-integration challenges, they realize that these challenges can arise from improper or poor design integration. In large, complex products, all three integration components may tax a firm's ability to achieve integration, leading to system instability.

Interestingly, all three components gained salience at different times during the program implementation. The division of labor decisions made as part of design integration needed to happen first. Poor decisions at this stage can lead to production integration problems. In novel and complex systems, it may be impossible to achieve perfect design integration *ex ante*; any observed production integration problems are fixed first by achieving better design integration. Supply chain integration issues are typically faced after the product design has stabilized and many technical issues in manufacturing are ironed out. Supply chain integration leverages the activity visibility generated for production integration and moves toward predicting and preventing integration issues rather than reacting to them.

Second, in contrast to past research focused on co-location and/or RSA as the primary tools for achieving integration, this study highlights the role played by a dedicated, centralized center specifically designed to achieve integration. As a tool, the integration center has become the brain behind Boeing's integration efforts. Specifically, our findings highlight the importance of two distinct types of *visibility* as critical mechanisms underlying integration.[16] As a centralized entity, the center increases visibility (activity and knowledge), thus enabling the prime contractor to achieve and maintain integration. Its effectiveness can be seen in improved integration performance and reduced co-location needs.

Third, analyzing the center's role helped clarify interrelationships among such integration tools as co-location, RSA, and authority. As noted, co-location is difficult and expensive to achieve in a globally distributed complex NPD project, and RSA's effectiveness as a tool is unclear when task requirements change. Our findings point to the indispensability of *some* co-location in such situations regardless of cost; we also found that co-location varied by partners' ability to accomplish their assigned tasks (e.g., Vought and Alenia required greater co-location than Spirit). As routines were established to promote production and supply chain integration to stabilize the system, the amount of co-location was gradually reduced, suggesting that a dedicated integration center can largely (but not completely) substitute for co-locating personnel at partner facilities.[17]

Also, past research has not explicitly examined whether co-location and RSA are complements or substitutes, though they are both important tools to achieve integration. Co-location enables visibility of activities at partner facilities and limited visibility of knowledge located in the two firms. RSA or social integration over time leads to increasing knowledge visibility. Specifically, RSA cannot fully substitute for co-location in complex projects because it cannot provide activity visibility. In this case, the changed task (build-to-performance versus build-to-print in earlier programs) further constrained RSA effectiveness. The integration center, however, was designed to provide both visibility of knowledge and visibility of activities.

[16] Prior work has referred to co-location, RSA, and normative and social integration as 'integration mechanisms.' To us, these represented tools and not mechanisms. Each of these tools increases visibility between the partners, which is the mechanism by which these tools facilitate achieving integration.

[17] One can think of the relationship between co-location and the integration center similar to the relationship between capital and labor in a (Cobb-Douglas) production function. Some co-location is necessary for efficient functioning, but the integration center can effectively substitute after a threshold minimum level.

DOI: 10.1111/j.2042-5805.2012.01050.x

Fourth, regarding the role played by authority, our preliminary findings add limited empirical traction to the largely theoretical debate over the role of authority in the knowledge-based view of the firm. The defining question in the theory of the firm literature is the boundary choice between pure markets and hierarchies. Kogut and Zander (1992, 1996) assert that firms are communities that enable knowledge exchange and coordination based on continuity of association and common identity, leading to a common language and higher order organizing principles. In contrast, Williamson (1991) argues that authority is important because it prevents haggling over gains/costs and reduces transaction costs.[18] Empirically distinguishing these assertions is difficult in practice because a firm is both a boundary of association *and* authority. Hence, it is not surprising that the empirical evidence is mixed.[19] The 787 program involves risk-sharing partners and lies in the *swollen middle* (Hennart, 1993) between pure markets and hierarchies. Thus, it provides an opportunity to examine the assertions raised earlier.

When Boeing acquired the Vought and GA facilities, the unified authority enabled the Charleston factories to merit the attention of the internal buyer in Everett, in order to approve coordination changes and integrate production, a task with which the external supplier had struggled. Integration also enabled investment in visibility-enhancing mechanisms in which some external suppliers were reluctant to invest. Also, Vought's Doty had complained about having the responsibility to integrate with other Tier 1 structural partners without the authority to mandate any changes, which technically should not have been a problem since the partners' incentives were aligned toward swiftly achieving effective integration. Our findings, therefore, suggest that authority (or bargaining power) may be necessary in generating requisite visibility for integrating activities. A dedicated integration center, such as the PIC, is only as useful as the visibility it helps generate.[20] This suggests that the visibility necessary for coordination is generated more easily in the presence of authority, a point that needs validation in future empirical studies.

Finally, these assertions have some very interesting implications for a firm contemplating a global strategy. On the one hand, researchers have suggested that the *raison d'être* for the MNE is to leverage economies of knowledge and learning across different geographies (Bartlett and Ghosal, 1989; Mudambi, 2011). An MNE that truly depends on integration across geographies for its competitive advantage is more likely to succeed if the headquarters played a strong role. On the other hand, a strong headquarters challenges subsidiary autonomy and flexibility (Birkinshaw and Hood, 1998; Mudambi and Navarra, 2004). So the international business research suggests that given such trade-offs, middle positions are unsustainable. But our findings suggest middle positions are sustainable if the HQ managers have the tools to generate visibility across the MNE network of subsidiaries.

Study limitations

This is one of the first inductive studies to examine a complex globally distributed NPD project. While our choice of program and industry may limit the generalizability of the findings, it has enabled us to take a more fine-grained approach to analyzing how global integration capabilities emerge in practice. Such detail would be difficult, if not impossible, to capture through large sample studies (Poole and Van de Ven, 1989). Given our objective of understanding the boundary conditions of existing theory, this approach was well suited to our research question. Also, some of the processes and mechanisms highlighted are generalizable across other complex globally distributed programs.

We recognize that there are numerous other important issues to the success of venturing into an NPD in a globally disaggregated supply chain. Given our interests and the thrust of the special issue, we restricted the scope of the article and focused extensively on activity coordination among actors and deliberately ignored other important aspects of new product development (such as financing models for

[18] Building on Williamson's work, Argyres (1999: 168) has speculated that 'some sort of hierarchical mechanism may be needed in the early stages of systems development and adoption in order to overcome inherent transaction cost and bargaining problems.'

[19] Some studies have found little difference between within-firm integration versus between-firm integration (Helper *et al*., 2000), while others showed that within-firm integration is superior (Almeida *et al*., 2002).

[20] From a variety of motivation considerations, partners may limit their facilities′ visibility to the systems integrator. Co-location is one means of overcoming such motivation challenges, as the collocated integrator's engineers can monitor the activities of partners. However, in a globally disaggregated program, this is a costly solution. In these cases, authority could remove potential impediments to achieving such visibility.

DOI: 10.1111/j.2042-5805.2012.01050.x

complex projects, project management issues, supplier selection, and the role played by risk in the initial design and subsequent reorganization of the airplane's program architecture). The aspects of the program not examined here are interesting avenues for future research.

Our primary informants were Boeing employees. Although we interviewed Boeing personnel who were directly involved in supplier integration issues at Vought, both before and after its takeover by Boeing, we did not interview other major suppliers, which is a limitation to our data. However, since we relied on media reports and comments by industry observers, we provide a balanced and accurate understanding of how events unfolded. Finally, we were not privy to other tools Boeing may have used to manage the program. Given the importance and complexity of this topic, it would be an excellent avenue for future research.

Past research has suggested that when a product's architecture is modular, knowledge integration from external sources is less difficult (Baldwin and Clark, 2000; Brusoni *et al*., 2001). But technological uncertainty and an incomplete understanding of interdependencies preclude modularity and increase misalignment risk (Ethiraj and Levinthal, 2004). It is possible that once the 787 production system reaches a level state and when interdependencies are better understood, greater modularity may be achieved. In other words, modularity may not be initially designed in a complex system; it may emerge with time, as the interdependencies are better understood. This topic should be reviewed for possible research when Boeing introduces its 787 derivate, the 787–9, within the next few years.

CONCLUSION

This article examined how to integrate globally distributed complex innovative projects by studying the Boeing 787 *Dreamliner* program. Whereas prior work has emphasized the need for co-location between partners and the formation of individual-level personal relationships to achieve coordination and alleviate opportunism concerns, such tools are not readily adapted to integrating work distributed across geographic and firm boundaries. We find that integration is facilitated by enhanced visibility between assembler and partners regarding the context of work and the locus of knowledge; we suggest that the integration tools identified in prior work effectively increase such visibility, and we argue how a dedicated integration center may increase visibility.

We also find that bargaining power is important to motivating partners to take actions that enhance visibility across firm boundaries. Taken together, these findings imply that (1) enhancing visibility is the mechanism that underlies all integration efforts and (2) under conditions of uncertainty, authority (or a close substitute), is necessary to enhance visibility and thereby achieve coordination even when incentives are aligned. These findings inform the lively debate between the transaction cost-based perspective and the knowledge-based view of the firm by suggesting boundary conditions for the latter.

ACKNOWLEDGEMENTS

We thank the Boeing executives for taking the time to share their insights. Specifically, we thank David Smukowski for connecting us with various executives at Boeing. We also thank Markus Becker, Anand Nandkumar, Torben Pedersen, seminar participants at the Copenhagen Business School, and the associate editor and three anonymous reviewers for their feedback in improving the article.

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