PAPERS

The Challenge of Innovation in Highly Complex Projects: What Can We Learn from Boeing's Dreamliner Experience?

Aaron J. Shenhar, *Technological Leadership Institute, Verona, New Jersey, USA*
Vered Holzmann, *Tel Aviv University, Tel Aviv, Israel*
Benjamin Melamed, *Business School, Rutgers University, Newark, New Jersey, USA*
Yao Zhao, *Business School, Rutgers University, Newark, New Jersey, USA*

ABSTRACT

Understanding the link between project complexity and innovation is highly pertinent. Yet, the challenge of innovative complex projects has received limited research attention and little theory development. This article provides a retrospective analysis of the difficulties experienced by Boeing during the development project of its highly innovative Dreamliner aircraft. Eventually successful, this project suffered extensive delays and cost overruns. The article analyzes the project's complex nature of innovation, while using several frameworks to provide an integrative view of its challenges and suggesting possible alternative ways to address them. Insights for complex project teams and future research directions are offered.

KEYWORDS: aerospace; innovation; complexity; project management; complex project and program management; Boeing 787 Dreamliner

Project Management Journal, Vol. 47, No. 2, 62–78

Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/pmj.21579

INTRODUCTION

Boeing Corporation, which was founded in 1916, has become one of the world's largest manufacturers of commercial aircraft, ranking now 27th on the Fortune 500 list. On September 26, 2011, Boeing publicly announced the delivery of its first 787 Dreamliner transporter to its first customer, All Nippon Airways. That event took place almost 40 months later than originally planned, after a long series of unexpected delays. The actual development cost of the project was estimated at about US$40 billion and was "well more than twice the original estimate" (Mecham, 2011). Adding to the difficulty was the discovery of a malfunction a year later in one of the aircraft's lithium batteries, which caught fire after takeoff. These problems led to months of grounding, imposed by the FAA (Federal Aviation Administration), of the entire Dreamliner fleet already in service.

Boeing's vision for the Dreamliner was to make it one of the most advanced commercial aircraft ever built and one of the most efficient to operate. However, its late delivery and early service problems were particularly troubling for a large corporation like Boeing, which is highly regarded as a leader in the aerospace industry and one of the world's most experienced aircraft manufacturers. However, the Dreamliner's late debut also provides an opportunity for the aerospace industry, and the research community at large, for retrospective in-depth learning.

In this article, we analyze the challenges that Boeing faced in this project and the lessons it learned while coping with them. By taking an innovation management perspective, our analysis offers ways to explain Boeing's experience, and possible ways to avoid similar failures in the future.

Our conclusion is simple. Boeing's delays and other problems *could have been minimized, if not prevented*. More important, a careful early analysis of the project's *innovation* challenges and potential difficulties might have predicted many of the problems that followed, and perhaps avoided some of Boeing's losses, including the resulting reputational damage.

After discussing our research method, the third section outlines the story of the Boeing 787 project.[1] The case story section describes the project's vision and the decisions made by the company through the project life cycle, then outlines the project's challenges and describes the project's development history, including the actions taken by the company in response to its delays. The next section, which is dedicated to innovation, includes a retrospective analysis of

[1]Please note that for consistency in this article, we use the term *project*, although large projects in the aerospace industry are also often called "programs," as they are indeed a collection of related projects (PMI, 2013).

the project's innovative challenges and a discussion on how these problems could have been avoided, or at least mitigated. We engage recent models of innovation and complexity, and point out where more theory development is needed. We conclude with a list of lessons that may be applied in future, large-scale strategic innovation projects, and suggest questions for future research.

Research Method

The Dreamliner project was one of the case studies in a multi-year study of the aerospace and defense (A&D) industry, which began in the 1990s (e.g., Tishler, Dvir, Shenhar, & Lipovetsky, 1996). In 2007, after Boeing announced its first 787 delay, we made the Dreamliner the focus of a dedicated in-depth longitudinal study. Between 2007 and 2013, we collected all publically available articles or posts about the Dreamliner project, as well as Boeing's history and the project's earlier decisions.[2] We systematically coded all material into categories such as business, performance, strategy, technology, planning, control, testing, and so forth. We read and coded nearly 800 articles and posts, and interviewed eight non-Boeing aerospace executives and reporters who offered their non-classified perspectives. When it became clear that studying this project required more than traditional project and innovation expertise, we increased our team by adding experts in supply chain management and operations. We conducted weekly research-team debates, dedicated to a specific category and its theory, and created discussion notes, which were then cross-analyzed to form the basis for our final analysis. Three independent scholars then reviewed our draft and offered comments and suggestions.

The Dreamliner Project

Initial Vision and Plan

The Dreamliner project was initiated in the early 2000s to take advantage of new technologies, including composite materials and electronic controls, with an effort to reduce fuel costs and noise levels and as a strategic preemptive move to compete with Airbus' 380 program (Useem, 2006). The Dreamliner project was launched in April 2004 with a planned delivery date during the first quarter of 2008. In retrospect, it seems that this schedule was highly unrealistic. By 2008, however, Boeing had already collected a backlog of more than 850 orders, at an estimated value of US$140 billion, which made the Dreamliner the most successful launch of any aircraft in history. A final configuration was selected in September 2005 and the design of major subsystems began in June 2006. The project opened its assembly plant in Everett, Washington, USA, in May 2007; however, its first test flight took place in December 2009, almost 18 months later than expected, and as mentioned, the first delivery took place some 40 months later than planned.

Dreamliner's Challenges

The Dreamliner was designed to be a revolutionary project in many respects: physical characteristics, technology, management style, financing, design and engineering management, quality assurance, and assembly processes. Many of these initiatives were intentionally taken on to benefit from new developments in aviation technology and to speed up design and development; however, as we will show, they posed unexpected challenges for both the company and the project team.

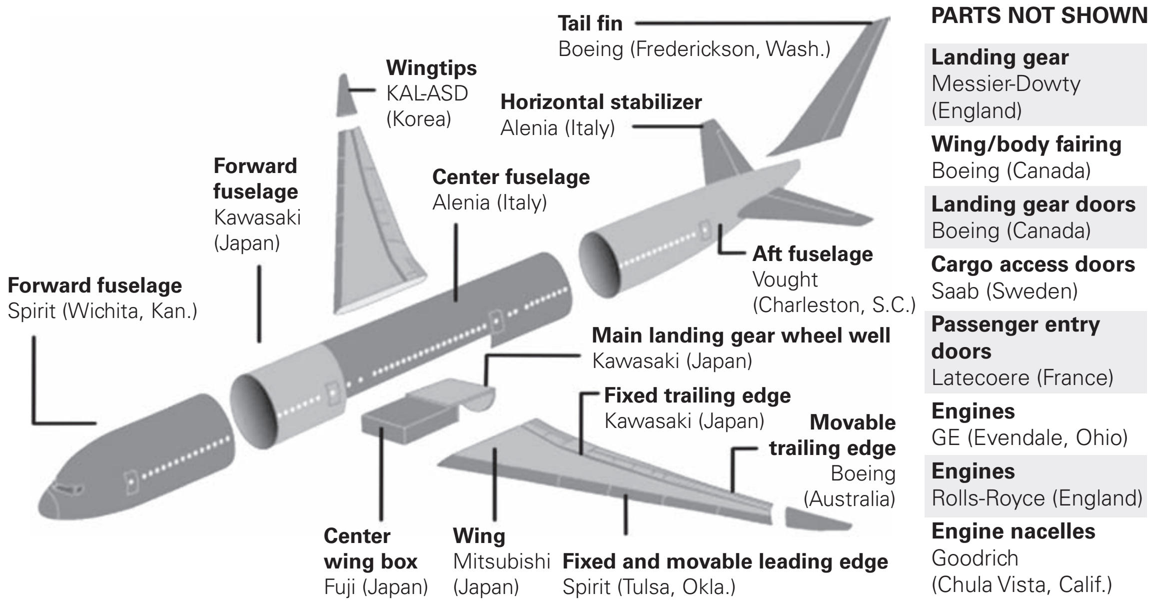
The first major challenge involved designing the aircraft's body using lightweight composite materials (chemical compounds made of carbon). This change was necessary, since the Dreamliner was to provide long-haul transportation for 250 passengers for about a 20% lower fuel cost (Ye, Lu, Su, & Meng, 2005). Although composite materials were not totally new, they were never used to such an extent in a large civilian aircraft (Teresko, 2007). However, this decision created a challenge to the design of the big fuselage, which is a multi-sectional cylindrical barrel covering the seating area of the aircraft. The new technology required more sections than previously used for aluminum-based fuselages. The result was that initial prototypes failed during the testing stage, forcing Boeing to redesign the body structure by adding more sections and scheduling more prototype testing, which added significantly to the schedule (Holmes, 2006).

The second technological change involved new kinds of avionics and computing systems that had never been used before on large commercial aircraft. They included the largest ever-used displays on any commercial aircraft (Ye et al., 2005), as well as replacing previous mechanical controls with electronic signal controls—a technology known as "Fly by Wire." Also new to commercial aircraft design, these technologies added to the project's delays by extending its wiring, installation, and integration processes (Holmes, 2006).

Boeing also adopted a new organizational paradigm for the development of Dreamliner and decided to outsource an unprecedented portion of the design, engineering, manufacturing, and production to a global network of 700 local and foreign suppliers (MacPherson & Pritchard, 2005). With more than 70% foreign development content, this decision turned Boeing's traditional supply chain into a *development chain* (Altfeld, 2010; Tang, Zimmerman, Nelson, & James, 2009). Tier-1 suppliers became responsible for the detailed design and manufacturing of 11 major subassemblies, while Boeing would only do system integration and final assembly. Figure 1 describes the project's major subassemblies and their tier-1 suppliers (Domke, 2008; Franck, Lewis, & Udis, 2009).

Furthermore, Boeing came up with a new risk and revenue sharing contract with its suppliers, called the "build-to-performance" model. According to the model, contract suppliers bear the non-recurring R&D cost up-front, own the intellectual property of their design, and get paid a share of the revenues from

[2]Please note that this article is based on publically available information and was not discussed or approved by Boeing.



Graphic research and design by David Badders, Seattle Post-Intelligencer. Sources: The Boeing Co., Vought Aircraft Industries Inc., GE Aviation, Rolls-Royce, Airbus, PPG Industries, Diehl Aerospace, Evergreen Aviation Technologies Corp. (EGAT)

Figure 1: 787 project's tier-1 suppliers.

future aircraft sales. Table 1 summarizes the main features of this model. Under the new model, the suppliers' roles are dramatically changed from mere subcontractors to strategic partners who have a long-term stake in the project. As we show later, however, this model created some risks, which caused extensive integration problems and additional delays.

Finally, Boeing employed a new assembly method. Subcontractors were required to integrate their own subsystems and send their preassembled subsystems to a single final assembly site. The goal was to reduce Boeing's integration effort by leveraging subcontractors to do more work compared with previous projects. However, many of these subcontractors were not able to meet their delivery schedules due to lack of experience in subsystem design and integration, as well as insufficient guidelines and training. As a consequence, parts and assemblies, which were sent to Boeing for integration, were missing the appropriate documentation, including instructions for final assembly.

Comparing the Project's Events to the Original Plan

The original plan of the 787 was to have all subassemblies completed and delivered by June 2007, have the maiden flight in August 2007, and make the first delivery by May 2008. On July 8, 2007, a rollout ceremony was held for the first Dreamliner (Norris & Wagner, 2009). However, the aircraft's major systems had not yet been installed, and many parts were only attached with temporary fasteners (Trimble, 2007). It was the first of several delays prior to the first test flight, which took place nearly a year and a half later than planned (Cohan, 2009; Kotha & Srikanth, 2013). With more than 60 canceled orders, Boeing had to pay its customers nearly US$1 billion in penalties for late delivery because the first aircraft were not sellable. See Table 2 for a detailed sequence of events (*The Seattle Times*, 2009).

Project Development Difficulties

Design issues were not the only causes of delays. Boeing listed addi-

Scope	Contractual Arrangement/Responsibility
System design and architecture	Boeing as main contractor
Detailed part design	Suppliers
Interface design	Boeing defines interfaces; suppliers provide detailed designs, and Boeing serves as referee
Selecting and managing tier-2 suppliers	Tier-1 suppliers
Intellectual property	Owned by suppliers
Non-recurring development costs	Amortized costs paid by suppliers from 787 revenue
Time of payments to suppliers	When 787 is certified and delivered to customers

Table 1: Boeing 787's build-to-performance model.

Year	Month	Events
2002	December	Responding to airlines' calls for more fuel efficiency rather than extra speed, Boeing drops its "Sonic Cruiser" concept. Much of the Sonic Cruiser's composite materials, avionics, and engine technology will reappear in the 787
2003	December	Everett, Washington, USA is chosen as the first assembly plant
2004	July	ANA places a 50-plane order
2005	September	Main features of the 787 airplane design are complete and detailed design work is sent to Boeing's global partners
	December	288 orders by the end of 2005
2007	June	A 0.3-inch gap was found at the joint between the nose-cockpit section and fuselage section, made by different suppliers. Engineers fixed it by disconnecting and reconnecting internal parts
	July	The first assembled 787 is rolled out at Everett, but unknown to the audience, it is a hollow shell
	September	**First delay**: three months. Due to shortage of fasteners and incomplete software
	October	**Second delay**: six months for first deliveries, three months for test flight. Due to unfinished work passed along by global partners and delays in finalizing the flight control software. Mike Bair, 787 program head, is replaced by Pat Shanahan
	December	346 orders by the end of 2007
2008	January	**Third delay**: three months for test flight. Due to unnamed suppliers and slow assembly progress at the Everett plant
	April	**Fourth delay**: six months, again for test flight; total of 15 months behind the original schedule for first deliveries. Due to continuing problems with unfinished work from suppliers
	September	A second machinists' strike begins at Boeing, lasting 57 days. The company struggles for a month afterward to get production back on track
	November	News emerges of a new, embarrassing and serious problem. About 3% of the fasteners put into the five test airplanes under construction in Everett were installed incorrectly and had to be removed and reinstalled
	December	**Fifth delay**: six months. Shanahan is put in charge of commercial-airplane programs, and Scott Fancher takes day-to-day operations lead on the 787 project. More than 900 orders by the end of 2008
2009	January–February	Middle East leasing company LCAL and Russian airline S7 group cancel 37 orders
	June	**Sixth delay**: test flight is postponed indefinitely. Due to a structural flaw at the wing-body joint
		Australian carrier Qantas cancels 15 orders
		Boeing writes off US$2.5 billion because the first three planes are unsellable and suitable only for flight tests
	July	Boeing announces that it will acquire the 787 rear fuselage assembly plant in Charleston, South Carolina, USA, buying out its partner Vought for about US$1 billion
	October	Additional 10 orders canceled. The total number of order reduces to 840
		Intensive talks between Boeing and the machinists' union end in acrimonious failure. Boeing announces the choice of Charleston, South Carolina, USA, as the second final assembly plant
	November	Boeing mechanics complete the wing-body joint fix. Engineers repeat the wing stress test, and the Dreamliner gets the green light to fly
2010	August	**Seventh delay**: Boeing delays delivery of the first aircraft by three months due to engine failure and availability issues
	November	Boeing halts Dreamliner tests after an onboard fire
	December	**Eighth delay**: Boeing delays delivery **indefinitely**—no delivery date given
2011	September	First aircraft is delivered (40 months total delay)
2013	January	Entire 787 fleet in service is grounded for months by the FAA due to battery problems

Table 2: 787 Dreamliner's sequence of main events.

tional reasons such as weight control, fastener shortages, incorrect installation, extensive delays in suppliers' work, and software development difficulties (McInnes, 2008). Following is a more detailed account of these reasons.

Fuselage design changes required altering joints between sections, as well as a strengthening wing design, resulting in an 8-ton increase in maximal takeoff weight. Boeing addressed this problem by additional and originally unplanned redesign cycles, exploring multiple weight savings, which saved nearly 2 tons. (Domke, 2008).

In addition, the project repeatedly experienced insufficient supplies of basic components, such as fasteners, frames, clips, brackets, and floor beams. The body design changes required a different sleeve fastener design on wings, leading to the delay of the first test flight of August 2007. With 60 weeks of production lead time, the main fastener supplier, Alcoa Inc., was unable to meet demand on time (Lunsford & Glader, 2007). Furthermore, some fasteners were incorrectly installed (Gates, 2008).

But perhaps the most troubling issue in the Dreamliner project was the inability of Boeing's suppliers to meet the project's demands. This resulted in "traveled work," where suppliers' work was passed along back to Boeing's Final Assembly Line (FAL). As Pat Shanahan, the second project director, put it: "*We designed our factory to be a lean operation. And the tools and the processes, the flow of materials, the skills of personnel are all tailored to perform last-stage high-level integration, check out and test. We thought we could modify that production system and accommodate the traveled work from our suppliers, and we were wrong*" (Komonews.com, 2015).

How Did Boeing Deal With Its Unexpected Challenges and Delays?

Faced with major delays due to redesigns, part shortages, incorrect installations, software delays, and even a union strike, Boeing initiated several bold actions to deal with these issues. Such actions eventually led to the introduction of what proved later to be a highly desired aircraft.

- In December 2008, Boeing opened a Production Operation Center in its Everett plant to better coordinate with its tier-1, as well as tier-2 and tier-3 suppliers. The Center's mission was to "monitor global production among suppliers, solve problems quickly and keep the program advancing" (James, 2009).
- Dreamliner's components and modules began testing right away at the original manufacturer's site before being shipped out to the next assembler. This way, Boeing was able to identify and solve problems when they occurred, rather than later, when their impact was detected.
- Since Vought turned out to be one of its least reliable suppliers, in 2009 Boeing decided to acquire Vought's interest in Global Aeronautica, and its operations in South Carolina for US$580 million.

An Innovation and Contingency Perspective on Complex Projects

A retrospective look at the project's challenges, suggests that most of them were rooted in the company's decisions to engage new (or innovative) techniques and practices often used for the first time. While strategically justified, it seems that the company needed better adaptation of organizational and development practices to the innovation introduced by these decisions.

Innovation can be viewed as the "application of better solutions that meet new requirements, in-articulated needs, or existing market needs" (Frankelius, 2009). The Organisation for Economic Co-operation and Development (OECD) (2005) defines innovation from an overall broad perspective as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations" (OECD, 2005, p. 46). Complexity, in turn, in most studies is related to a large number of distinct and independent elements (Williams, 1999). Following these definitions, it is conceivable that Boeing's challenges were a result of a combination of multiple innovations in its Dreamliner development project. Thus, in the following discussion we describe the relevant literature on innovation and project management, which will be used for analyzing Boeing's experience and explaining the challenge of innovation posed by this project. We then use this analysis to depict possible alternative ways to manage such kinds of highly complex innovations.

As the Theory Suggests, One Size Does Not Fit All Innovations

One of the early studies of innovation conducted by Marquis (1969) was dedicated to exploring the differences between two types of innovation: *incremental* (a small change in an existing product) and *radical innovation* (a change based on a completely new idea). This distinction appears often in many studies (e.g., Baker & Sinkula, 2007; Balachandra & Friar, 1997; Chao & Kavadias, 2008; Gemünden, Salomo, & Hölzle, 2007; Germain, 1996; Kock, Gemünden, Salomo, & Schultz, 2011; Leifer et al., 2000). Marquis (1969) also mentioned a third type, *system innovation*, which relates to large complex efforts (systems) that combine many new and/or improved ideas in one big system development project, such as aircraft, communication networks, or space programs; however, he did not investigate this kind of innovation in detail in his study. The concepts of *exploitation* versus *exploration* emerged later (March, 1991), essentially distinguishing between two types of learning: *improvements* or *modifications of existing ideas* and *introduction of fundamentally new ideas* (Benner & Tushman, 2003; Danneels, 2002; Gatignon, Tushman, Smith, & Anderson, 2002). Innovation studies have also expanded in additional directions, such as new product development (Chen, 2015; Salomo, Weise, & Gemünden, 2007), open innovation (Chesbrough, 2006; Gemünden et al., 2007), portfolio management (Beringer, Jonas, & Gemünden, 2012; Kock, Heising, & Gemünden, 2014; Unger, Rank, & Gemünden, 2014), or other industries such as automotive (Lenfle & Midler, 2009).

Another well-established and relevant concept is structural organizational contingency theory, which suggests that organizations must find the right *fit* between problem and context and must adapt their structure, processes, and practices to the unique environment of their task. This idea implies that different kinds of organizations functioning in distinct environments must be structured and managed in different ways (Benner & Tushman, 2003; Burns & Stalker, 1961; De Brentani & Kleinschmidt, 2015; Drazin & Van de Ven, 1985; Hanisch & Wald, 2012; Howell, Windahl, & Seidel, 2010; O'Connor, 2008; Pennings, 1992; Ritter & Gemünden, 2003). Scholars have often suggested that organizations that perform more innovative tasks would be different from organizations which develop more routine products (e.g., Abernathy & Utterback, 1978; Burgelman, 1983; Dewar & Dutton, 1986; Drazin & Van de Ven, 1985; Galbraith, 1982; Perrow, 1967; Thompson, 1967).

Correlations between structural and environmental attributes have been well studied when the organization is the unit of analysis. However, they have only entered the realm of project management in the last two decades. The argument was that projects can be seen as "temporary organizations *within* organizations" and thus may exhibit variations in structure based on context and environment (Lenfle, 2008; Lundin & Söderholm, 1995; O'Connor & Rice, 2013; Payne & Turner, 1999; Shenhar, 2001).

The evolution of project management contingency theory and its relation to innovation was characterized by the introduction of specific context factors, which would distinguish projects by different dimensions, leading to specific contingency decisions (Hanisch & Wald, 2012). For example, Henderson and Clark (1990) have used a 2 × 2 matrix to distinguish between the components of a product and the ways they are integrated. Wheelwright and Clark (1992) have classified projects based on product and process types; Turner and Cochrane (1993) have grouped projects based on how well their goals and their means are defined; Youker (2002) has grouped projects based on product type; and Pich, Loch, and De Meyer (2002) have used a project's information adequacy (or level of uncertainty) to distinguish between three strategies: instructionism, learning, and selectionism. Shenhar and Dvir (2004, 2007) have used four dimensions to distinguish among projects: novelty, technology, complexity, and pace, and have shown how this categorization can be applied to innovation as well. It is interesting to note that the connection between projects and innovation is getting more and more attention recently, as demonstrated first in the 2007 IRNOP conference dedicated to this link (Brady & Söderlund, 2008). Consecutive articles discuss various aspects of innovation and project portfolio management. For example, Killen, Hunt, and Kleinschmidt (2008) studied Australian companies and found that project portfolio management practices are very similar for new service and tangible product development project portfolios. Biedenbach and Müller (2012) studied the relationship of innovative capabilities and long-term project success, whereas Sicotte, Drouin, and Delerue (2014) suggested a set of six critical capabilities for innovative companies managing successful projects. Unger et al., (2014) reported that corporate innovation culture and national-level culture are related to dimensions of project portfolio success, and Meifort (2015) reviewed the current research on innovation portfolio management and categorized it into four perspectives: optimization, strategy, decision making, and organization. The topics of complexity and uncertainty in projects have been often used interchangeably. For example, Geraldi, Maylor, and Williams (2011), when analyzing 25 notable papers, have referred to "complexity in projects" versus "complexity of projects" by suggesting an umbrella typology of five different dimensions of complexity: structural, uncertainty, dynamics, pace, and sociopolitical. In contrast, Howell et al. (2010) have presented uncertainty as the most common theme in the study of project contingency theory (PCT), followed by complexity, team empowerment, criticality, and urgency, whereas Bosch-Rekveldt, Jongkind, Mooi, Bakker, and Verbraeck (2011) have demonstrated the elements that contributed to project complexity by introducing the technical, organizational, and environmental (TOE) framework of complexities.

Based on these and other studies, four current conclusions about the state of knowledge of PCT emerge. First, just as for sustained organizations, "*there is no one best way*" for projects as well, and "*one size does not fit all*." Second, no generally accepted framework has emerged thus far to support the analysis of highly complex and innovative projects. Third, most emergent frameworks are theoretical or literature-based, with only a few grounded by empirical evidence. Fourth, research often offers limited prescriptive ideas on actually managing innovations. However, as claimed, "for practitioners a project's complexities can be used as a starting point for a reflection on the challenges a project faces, or will face, and the development of strategies to cope with them" (Geraldi et al., 2011, p. 983).

Analysis

Could Contingency Methods Help Prepare Boeing for Its Challenges?

As we have seen, Boeing's difficulties were a result of the following major challenges: The use of newly developed technologies, outsourcing a large extent of design to numerous, less experienced subcontractors (and creating a development chain), a new business model of revenue sharing, and a new assembly model. As claimed earlier, these strategies probably helped retaining Boeing's competitive positioning by taking advantage of modern technologies, and practices, but their execution was less than optimal.

In reviewing the current state of knowledge, no single available framework seems comprehensive enough for analyzing the spectrum of innovation challenges in a highly complex project such as the Dreamliner. To enrich the analysis, and complement possible limitations in any single model, we combined three frameworks offered by different authors: Pich et al. (2002), Shenhar and Dvir (2004, 2007), and Geraldi et al. (2011), thus creating a broader perspective. We selected these frameworks based on the following criteria: the framework must offer practical implications for project innovation teams; it was based on empirical evidence, not just theory; or it adds a factor that is not covered by other models. The following section describes each model in detail and its accompanying discussion outlines the lessons that could be derived for Boeing's project. In a later section we combine all these lessons into one integrated overview.

Pich et al.'s Categories of Project Learning

Pich et al. (2002) characterize projects based on the degree of information available upfront to the project teams. Each of their recommended three types of projects requires a different project management strategy as described below:

- **Instructionist project** is a project where most of the information needed for planning is available, and the project team has a good understanding of the "best policy" that has to be implemented. Planning an instructionist project mainly involves optimization that is focused on the critical path and risk management. The instructionist project primarily exploits known information and does not need to deal with high levels of uncertainty.
- **Selectionist project** is a project where there is not enough information to define an optimal policy; the project team is faced with a higher level of uncertainty, and it cannot accurately anticipate the results of its actions. Rather than exploit existing knowledge, the team is encouraged to explore; plan multiple trials and prototypes, while executing them simultaneously; and then select the best performing solution. From this point on, the project could be managed as an instructionist project.
- **Learning project** is a project susceptible to unforeseen events that might influence its course. In this environment, there is little benefit in detailed planning of the entire project, because the unforeseen might alter its course and force the team to learn and continuously readjust the plan. While each project needs a clear vision, its detailed planning can only be done for the nearest tasks and must be updated with progress.

In the Boeing case, the technologies of composite materials and "fly by wire" were new to this family of company products and this required an upfront analysis of the level of uncertainty and the allocation of sufficient time for testing and redesign. Similarly, the extensive outsourcing of design for the first time, as well as the new business model, required a slower pace of adaptation and learning of the new practices by all factors. However, Boeing employed what looks like an instructionist strategy (Pich et al., 2002), which is based on a low level of upfront uncertainty, such as construction, where activities, time, and cost are essentially predictable, and no surprises are expected. It does seem, however, that this project would require a selectionist style of project management. Such a style would ensure that the project is ready to acknowledge its upfront level of uncertainty and allocate sufficient resources for repetitive designs, prototype building, and testing before the final design is selected. It would also ensure enough time for training and certifying the project's subcontractors as well as adjusting the newly implemented business model.

Shenhar and Dvir's Diamond of Innovation

The Dreamliner's project innovative challenges could also be analyzed by using the "Diamond of Innovation" model. Based on a study of over 600 projects, the "Diamond of Innovation" provides a framework for project classification (Shenhar & Dvir, 2004, 2007). Each one of its dimensions of *novelty*, *technology*, *complexity*, and *pace* consists of four possible project categories, and by selecting a category in each dimension, one creates a specific diamond-shaped view for each project, which serves as a project classifier. Once a classification is selected, the model helps identify the unique impact of each dimension, and provides recommendations for a preferred style of management. The Diamond of Innovation dimensions and their impact on a project are summarized in Table 3.

Using the Diamond of Innovation implies that the Dreamliner project could be classified as outlined below. (We then discuss the fit between the actual management and the required style based on this classification):

- **Novelty**: From its customers' perspective, the Dreamliner was a generational change in an existing line of previous commercial aircraft built by Boeing. That would place it at the *Platform* level of novelty, which really did not create a unique challenge to the company that made all the strategic decisions needed for a new platform. However, there was another challenging aspect of novelty. The new "build-to-performance" business model, however, was unfamiliar to the company and its subcontractors. As major stakeholders, they can be considered as "users," and for them it was an unknown experience. That challenge would move the novelty to a "*new-to-the-market*" level, which suggests that the implementation of the new model would require pilot testing and repetitive model modifications until the final version was established and fully understood.
- **Technology**: The technology of composite materials was new to the commercial aircraft industry, and no prior experience existed on how to design

Novelty: Market Innovation—how new is the product to the market, users, and customers. Novelty level impacts market-related activities and the time and effort needed to define and freeze requirements (a higher novelty would delay this freeze)	• *Derivative:* Improvement in an existing product (e.g., a new color option in an MP3 player, the addition of a search feature in a software program) • *Platform:* A new generation on an existing product line (e.g., new automobile model, new commercial airplane) • *New-to-the-market:* Adapting a product from one market to another (e.g., first PC, consumer's microwave oven) • *New-to-the-world:* A product that no one has seen before (e.g., the first Post-it note)
Technology: Technological Innovation—how much new technology is used. It impacts product design, development, testing, and the requisite technical skills (a higher technology level requires additional design cycles and results in a later design freeze)	• *Low-tech*: No new technology is used (e.g., house, city street) • *Medium-tech*: Some new technology (e.g., automobile, appliances) • *High-tech*: All or mostly new, but existing technologies (e.g., satellite, fighter jet) • *Super high-tech:* Critical technologies do not exist (e.g., Apollo moon landing)
Complexity: Level of System Innovation—represented by the complexity of the product or the organization. Complexity impacts the degree of formality and coordination needed to effectively manage the project	• *Component/Material:* The product is a discrete component within a larger product, or a material • *Assembly:* Subsystem performing a single function (e.g., CD player, cordless phone) • *System:* Collection of subsystems, multiple functions (e.g., aircraft, car, computer) • *Array:* Widely dispersed collection of systems with a common mission (e.g., city transit system, air traffic control, Internet)
Pace: Urgency of the Innovation—How critical is your time frame. It impacts the time management and autonomy of the project management team	• *Regular:* Delays are not critical (e.g., community center) • *Fast-competitive:* Time to market is important for the business (e.g., satellite radio, plasma television) • *Time-critical:* Completion time is crucial for success by exploiting a window of opportunity (e.g., mission to Mars, Y2K) • *Blitz:* Crisis project—immediate solution is necessary (e.g., Apollo 13, September 11)

Table 3: Diamond of Innovation: definitions, dimensions, and project types.

and integrate it into a large wide body such as the 787. Similarly, the technologies of electronic controls ("fly by wire") were also new in the commercial aircraft sector. The innovative use of these technologies placed the Dreamliner in the *high-tech* category of innovation. In contrast, previous commercial aircraft such as the 777, which had used traditional aluminum body materials, would be classified as *medium-tech*. The ramifications of such innovative technologies suggest that this project required a different approach than that used in Boeing's previous generations. The immature technologies required additional time, more testing, and additional design-build-test cycles, as well as more prototyping. Such additional work was not planned in advance, requiring elaborate decision-making processes, and additional design resources (which were later added to the program).

- **Complexity**: Typically, most aircraft-building efforts can be considered *systems* on the dimension of complexity. The Dreamliner project, however, added a significant amount of complexity to the effort. Management's decision to outsource an unprecedented amount of design and development work to hundreds of subcontractors worldwide required an enormous amount of coordination and clear rules in work procedures as well as documentation. We propose that such complexity pushed the program from the *system* level to the *array* category, which requires extensive coordination and formality. The ramifications for the project were significant. What appears to be missing in this case was a detailed and elaborate system of vendor education, training, and verification that these vendors can actually do the job. In addition, Boeing had to invest in a highly formal and strict policy for vendor behavior, standards of work, and coordination. Preparing these formal rules and procedures required an extensive investment of time for building the complex management and control system. Array projects are often conducted across national borders and cultures, requiring them to find specific ways to overcome language and cultural differences. It seems that Dreamliner needed to implement more of these efforts upfront.
- **Pace**: The Dreamliner project was expected to be in the market in time to face and benefit from the growing demand. That would rank this project at the *fast competitive* level. Indeed, Boeing intended to treat the project as fast competitive, but faced with unexpected delays, the pace often seemed even faster.

Based on these observations, we classify the Dreamliner project as a *platform/new-to-the-market*, *high-tech*, *array*, and *fast competitive*, leading to a specific style of management for this classification. However, a careful analysis of the program's actual style was different along the dimensions of technology and complexity. Specifically, the actual approach chosen for managing novelty was closer to *platform*, instead of *new-to-the-market*, *medium-tech* approach, instead of *high-tech*, and the one chosen to manage complexity was closer to the category of *system* rather than *array*. Figure 2 is a visual depiction of the gaps between the required management style (bold diamond) and its actual counterpart (dashed).

Geraldi et al.'s Typology of Complexity

Based on an extensive literature survey, Geraldi et al. (2011) have adopted a broad perspective to the idea of complexity, and thus identified five dimensions of a project's complexity: structural complexity, uncertainty, dynamics, pace, and socio-political complexity. Two of them—dynamics and socio-political complexity—were not covered by the frameworks used earlier and may add new insights to the analysis.

- **Structural complexity**: Structural complexity relates to a large number of distinct and interdependent elements. It is impacted by size, variety, and interdependence of the elements.
- **Uncertainty**: Uncertainty represents the gaps between the amount of information required to make a decision and what is available. Uncertainty has an intrinsic relationship with risks, but as the literature suggests, there may be different kinds of uncertainty, such as uncertainty of goals and uncertainty of methods (Turner & Cochrane, 1993).
- **Dynamics**: Dynamics refers to changes in factors as goals or specifications. When changes are not well communicated or assimilated by the team, such changes may lead to high levels of disorder, rework, or inefficiency. Projects may not only change "outside-in" but also "inside-out," where teams may change their constitution or motivation, or internal politics may take over.
- **Pace**: Pace relates to the temporal aspects of a project. It represents the urgency and criticality of time goals. Pace essentially refers to the rate or speed at which produces should be delivered.
- **Socio-political complexity**: This kind of complexity relates to the problems involved when managing stakeholders, such as lack of commitment, or problematic relationships between stakeholders, as well as those related to the team. Issues that are often mentioned in this category include "complexity of interaction" between people and organizations, and differences of languages, cultures, and disciplines. It also refers to the complexity of the problem situation itself and the complexity of the human and/or group factor. Overall, this factor emerges as a combination of the political aspects and emotional aspects involved in projects.

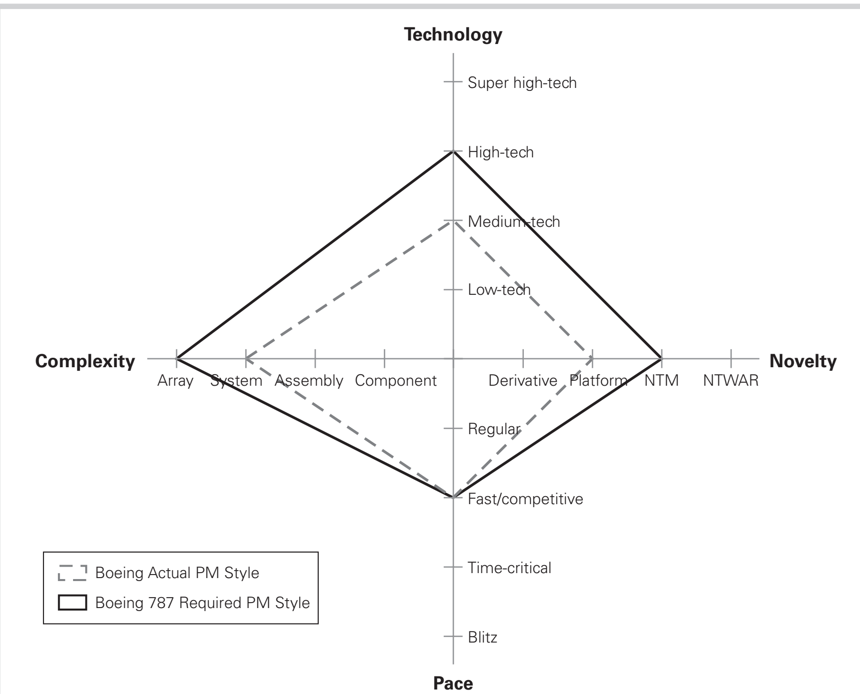


Figure 2: 787 project's Diamond of Innovation.

Geraldi et al. (2011) do not discuss specific impacts of each complexity dimension on project management, but rather, indicate that the assessment of project complexity could affect such items as the choices of competitive priorities, different project management methodologies and tools, managerial capacity development, or identifying problems in troubled projects. Furthermore, they note that the assessment of the type of complexity in projects is often subjective and will be influenced by the project manager.

Perhaps the most significant contribution of Geraldi et al.'s work (2011) is the proposition that complexity dimensions are frequently interdependent. For example, they indicate that high uncertainty may increase the level of dynamic complexity, which will bring increased structural complexity. Similarly, high structural complexity may lead to increased socio-political complexity, and high socio-political complexity may lead to increased levels of change and uncertainty. These interdependencies are clearly noticeable in the case of Dreamliner, and are outlined in the following discussion.

Geraldi et al.'s model (2011) may offer further insights into the analysis of Boeing's Dreamliner challenges, particularly with regard to the dynamics and socio-political complexity dimensions. The significant number of changes that were required in order to get the project back on track increased the degree of the dynamics compared to the original intentions. These dynamics required continuous adjustments of the project's organizational structure, design, and testing processes, additional resources and modified processes, not to speak of the added resources. They also caused several changes in leadership during the development period. Once again, one may claim that, had the company originally assessed the degree of innovation in technology and complexity, the original plan might have been more realistic and thus may have avoided much of the unplanned dynamics.

The last dimension of socio-political complexity is also meaningful. Boeing's intentions of outsourcing design to a large network of subcontractors and the new "build-to-performance" incentives model created a high level of additional complexity. Subcontractors had difficulties adjusting to Boeing's advanced design requirements, which were augmented by geographical distances, language, and cultural differences. In retrospect, analysis of Geraldi et al.'s model suggests that the project should have been better prepared for these kinds of complexities, which resulted from its business-related decisions. Such preparations would require an intense process of subcontractors' education about Boeing's requirements and design standards, followed by a tight system of coaching, reviewing, controlling, and on-going communication with its subcontractors.

Combined Lessons from the Three Models

As we have seen, analyzing the Dreamliner project using different innovation models may help explain the company's difficulties and suggest alternative ways that could have prevented some or all of these delays. Overall, a careful upfront analysis of the project during the planning process would look for all the new practices that distinguish this project from its predecessors, and select the mitigation techniques that would deal with these challenges upfront. Table 4 summarizes the combined lesson that we derived from our analysis, along with possible alternative activities that might have prevented the difficulties.

A combined analysis using all three models offers a more in-depth understanding of the project's challenges than using one model alone. Specifically, we discuss these combined insights using the two major perspectives of uncertainty and complexity, as well as their interdependencies. First, Pich's et al. (2002) model shows that the project adopted an instructionist strategy, which is based on relatively low levels of uncertainty, instead of the selectionist strategy that is typically required in cases that involve a higher level of uncertainty. Shenhar and Dvir's model (2007) analysis confirms this observation, by making a distinction between two types of uncertainty—novelty and technology. In terms of novelty, Boeing treated the uncertainty faced by its stakeholders (subcontractors) as "platform," where in most cases the experience of a previous generation is essentially repeated. However, in this case, for Boeing's stakeholders, the design and development experience was new and its novelty in our opinion should be considered as "new-to-the-market." Similarly, by introducing several key new technologies, Boeing has apparently lifted technological uncertainty from a "medium-tech" to a "high-tech" level; its managerial practices, however, were in our judgment, more typical of a "medium-tech" level.

From the complexity standpoint, we may conclude that the project's complexity was higher than it was in Boeing's previous generations due to the decision to share the design work with an extensive number of subcontractors. Shenhar and Dvir's (2007) model would suggest that this project should thus be seen as an "array"; however, our observation suggests that its actual management practices fit better with the "system" level, where everything is done in one location and in one organization. In reality, we believe that the integration and communication needed for this extensive worldwide effort suggests that this project should have been treated as an "array." Geraldi et al.'s two dimensions of complexity dynamics and socio-political complexity only strengthen this analysis (2011). Based on our observation, Boeing treated the project as having a low level of dynamics and socio-political complexity, as if things are quite stable and the cultural environment is mostly homogeneous. However, the need to make an extensive number of changes during the development and communicate them with a large collection of subcontractors around the world, have increased, in our view, both the dynamics and the socio-political complexities from low to high.

Finally, Geraldi et al.'s interdependencies of dimensions are also seen in the other two models. When an instructionist strategy (Pich et al., 2002) is replaced by a selectionistic strategy, or when novelty or technology shift from platform and medium-tech to new-to-the-market and high-tech, both the dynamic and socio-political uncertainties advance from the low to the high levels. A similar argument holds true for the shift from system to array in Shenhar and Dvir's model (2007). In sum, as one can see, each model offers a slightly different analytical perspective, but collectively, we believe, the multi-model analysis indeed enriches our understanding of the project's challenges and potential lessons.

Discussion

Boeing's confidence in its past experience and record of success perhaps led project leaders to believe that the new project would be as successful as before. Based on the above analysis, however, we demonstrated that the challenges and scope of innovation were probably underestimated. The level of new practices required to manage design subcontractors and the extent of technological innovation were much higher than in its previous commercial aircraft projects. The effort involved in integrating new technologies required a much

Model Used for Analysis	Variable	Actually Used	Recommended	Implications and Discussion
Pich et al., (2002)	**Project management learning strategy**	Instructionist strategy is used for a project where most of the information for planning exists and there is a low level of uncertainty	Selectionist strategy is used where there is insufficient information for planning, due to high level of uncertainty	Faced with extensive levels of uncertainty, the project had to create a master plan with additional prototypes and tests before final decisions could be made. This would probably extend the original schedule, but eventually produce a more realistic plan that would reduce the final cost
Shenhar and Dvir (2007)	**Novelty**: Market or User (Stakeholder) Uncertainty	Platform—A next generation in an existing line of products	Platform and New to the Market—To customers, the product was indeed a Platform. But for subcontractors, Boeing's design and incentives model were "New to the Market"	The company had to train and coach subcontractors in its design methods as they learned to address new design and development practices. In addition, the new incentives model was rarely used in the industry and was new to Boeing's overseas partners. The model had to be carefully implemented with small pilots where both sides experience it and gradually learn how to work effectively with it
	Technology: Extent of using new technology—level of technological uncertainty	Medium-tech—where most technologies are well known with a small number of changes	High-tech—the project is using new technology that was recently developed and rarely used before in such kinds of projects	The high-tech level required planning at least three to five design cycles, and an increased number of prototypes that would enable testing the new technologies design and integrate it with the entire aircraft
	Complexity: How complex is the product and/or the organization that is creating it	System—a collection of subsystems that is creating a multifunctional product	Array (System of Systems)—a large collection of systems or organizations, working together for a common mission, often widely dispersed geographically	Boeing's development chain created an array of companies around the world that was engaged in design and development. To succeed, such an array must be carefully coordinated with clear rules, standards, and common forms of documentation, reporting, and communication. These elements are typically prepared before the array is launched worldwide
Geraldi et al., (2011)	**Dynamics—** Extent of changes	Low Dynamics—not too many changes are expected and the process is executed as planned	High Dynamics—where many changes are common and continuous adjustments are needed	The high levels of uncertainty led to numerous changes, which increased the dynamics level of the project
	Socio-political Complexity— Complexity due to sociological differences and political influences	Low level of socio-political complexity, as in previous projects where most of the work was done inside	High level of socio-political complexity, which resulted from the need to coordinate the large collection of different cultures and languages	The resulting high socio-political complexity required extensive attention to the cultural and languages differences. The company had to prepare an extensive training program to make all managers aware of these differences and teach them strategies to cope with them

Table 4: Dreamliner's innovation challenges analysis.

higher allocation of time and other resources than originally planned. Lacking an established framework for such allocations, planners found out later that they needed to add more design cycles to the original plan, build more prototypes, and conduct additional testing. Later corrective actions led to delays and higher cost, which may have been avoided had these challenges been addressed in advance.

In addition, from an organizational standpoint, the development effort of the Dreamliner was more complex than in previous projects due to the innovation involved in outsourcing much of the design and development, as well as a new incentives model. The project lacked sufficient organizational support systems for managing the new and highly complex network of inexperienced suppliers. Here, too, such systems were eventually put in place, but at a much higher cost than if implemented at inception. The interface between technological innovation and organizational complexity was also significant. The time required for integration and for redesign iterations *across* multiple firms was underestimated. Boeing originally allocated only two months for system integration before scheduling the first flight. In retrospect, that time was much lower than needed.

Similarly, from a strategic standpoint, we believe that the company was not fully ready to manage the innovative business model of Build-to-Performance. Such innovation required the burden of fully controlling strategic outsourcing, supplier selection, contracting, monitoring, testing, and quality control, as well as addressing the cultural and distance differences; however, only a few of these activities were completed before the project was launched. Our analysis indicates that the company should have selected suppliers more carefully based on their R&D capabilities, level of commitment, and financial strength. Furthermore, drawing from the analysis, we believe that the company would have greatly benefited by initiating an extensive training program for its subcontractors, making sure they were ready to take on the challenge before they could commit to undertaking the design and development work.

Tactically, Boeing found it difficult to resolve the incentive issues underlying traveled work by linking suppliers' performance to suppliers' gain. The models may indicate that Boeing should have revised the risk-revenue sharing contract to provide mid-course financial incentives for suppliers to work faster and better, while penalizing them for delays and unnecessary traveled work. In addition, open communication and well-planned monitoring and controlling suppliers' processes could have effectively reduced traveled work, ensuring only properly completed work would pass on to the next stage, while helping detect problems early on.

What Can Companies and Researchers Learn From Boeing's Experience?

Innovation is clearly one of the major drivers of economic growth; yet, it is risky and often ends up in disappointing results or failure. For example, Tepic, Kemp, Omta, and Fortuin (2013) reported 16 failures out of 38 innovation projects conducted by European industry companies and Baron, Esteban, Xue, Esteve, and Malbert (2015) discussed the cooperation between processes related to system development and project management in developing new products. Empirical innovation studies have often focused on small- or medium-sized projects that built tools, appliances, cars, or software; yet, as mentioned, highly innovative and complex projects have received less attention. Complex projects involve a substantial degree of difficulty due to a large number of components and technologies, involvement of numerous organizations, extensive communication and coordination requirements, and widely dispersed teams. When it comes to innovation, the challenge is even greater, leading to higher risk, which often requires adapting specific management processes during the development project. As Gann and Salter (2000), Hobday and Rush (1999), and Davies and Mackenzie (2012) indicated, the management of complex projects, which involve an integration of multiple components, calls for understanding and implementation of practices derived from the company strategy, management practices, and organizational processes. While the management of innovation in highly complex projects is still not fully investigated, most traditional project and program management tools rarely deal with planning and managing the project's innovation. Such models tend to assume that projects mostly are linear, certain, and predictable, and pretty much, "one size fits all." Well-established traditional risk management tools are aimed at protecting a project when things might fail, hence providing a preconceived remedy (or mitigation) when things are going wrong. Based on our assessment, we suggest that innovation management, however, is not about "what can go *wrong*?" It is about figuring out "how long will it take to get it *right*?"

Conclusions

Our analysis has shown that highly complex and innovative projects may benefit from adopting a contingency approach for their planning and execution processes. One of the main lessons of this and similar contingency studies is that "*one size does not fit all innovations.*" Companies as well as researchers may explore more ways to understand the differences among projects and among different innovations. The three models for the analysis used in this article have demonstrated possible ways to identify such differences and adapt optimal management strategies. Pich et al.'s (2002) model shows how different levels of upfront information impact the project management strategy; for a best fit, they recommended selecting between the instructionist, selectionist, and learning strategies. The Diamond of Innovation (Shenhar & Dvir, 2004, 2007) provides a possible framework for analyzing innovation at the project level by integrating project management and innovation management. Classifying a project using the Diamond of Innovation dimensions, leads to specific decisions based on each dimension. For example, the model suggests that a high-tech project must include at least three cycles of design, build, and test. It also suggests that such projects need to allocate about 30% of the time and budget as contingent resources beyond a typical traditional plan. Similarly, an array program must prepare clear guidelines and coordinating mechanisms to make sure all components and participating companies are using the same terminology and standards, are similarly trained, and are effectively communicating. Geraldi et al.'s (2011) model specifically addresses five kinds of complexity, adding the dynamics and socio-political dimensions to previously existing models. Low or high levels in these dimensions require specific attention to their impact.

These models however, may not be the only ways to deal with innovation. For example, as early as 1984, Saren (1984) suggested classifying existing models of innovation according to five types: departmental-stage models, activity-stage models, decision-stage models, conversion process models, and response models. More recently, Garcia and Calantone (2002) identified the constructs that are related to marketing and technological perspectives, at the macro and micro levels of a project. They presented a comprehensive list of constructs based on radicalness, newness, uniqueness, and complexity. Undoubtedly, additional models of innovation may be developed and applied to the fast-changing world of innovation.

A second clear conclusion we derived from our analysis is that there is currently no single comprehensive model to understand and analyze the entire spectrum of innovation challenges in highly complex projects such as the Dreamliner. After accepting the reality that one size does not fit all, practicing companies may still need to rely on a combination of models to understand the extent of innovation in a project and find the optimal ways of managing them. Furthermore, using several models of analysis may shed different lights on understanding the challenges of a complex project. Contingency aspects could be multifaceted and interactive, and no single or best model provides an overall direction or conclusive recommendations at this time. Different models may also be complementary to each other, and if used together, they may compensate for weaknesses or limitations of any single model alone.

This study may also offer new directions for further research. As we mentioned, research communities have typically focused on smaller scale projects. The more complex projects have received less attention thus far. There is clearly a need to develop comprehensive models of innovation in highly complex projects. Such models will establish a new basis for understanding the links between complexity, uncertainty, and innovation. We contend that future researchers may find ample opportunities for studying this important and intriguing field.

One of the main directions for future research is seeking additional and perhaps more refined models to distinguish among projects. Such distinctions may be of two kinds: First, identifying the major dimensions that characterize typical qualities of projects. For example, future researchers may find additional types of uncertainties and complexities in projects. The challenge would be to identify what really characterizes contingencies and how to avoid overlaps and contradictions. The second kind of investigation may be aimed at finding different scales or ranks for each dimension. Classical low-high distinctions seem to have been replaced in recent years by more refined frameworks involving three, four or more levels of distinction.

Once new dimensions and types are offered, another main direction for future studies is identifying managerial implications for different kinds of projects on each dimension. Such implications may relate to the organizational issues of complex projects. For example, should highly innovative projects be organized differently from lower innovative efforts? Differences may also be found in planning, monitoring, team selections, managerial qualities, subcontracting, stakeholder management, and many others.

Finally, this study is not free of limitations. First, using one case study is clearly insufficient to offer a comprehensive view of the industry or other complex innovative projects. Second, our research method, which relied on open sources, has a potential limitation of missing an in-depth better understanding of the project's internal dynamics and managerial processes taken by Boeing. Third, in this kind of study, one can only analyze the difficulties encountered during the project. It is impossible, however, to predict what may have happened if Boeing had taken a different approach. Thus, all potential remedies suggested at this stage can only be seen as possible options without a clear guarantee for better success. Finally, the lack of one comprehensive acceptable theory and the need to rely on a collection of models might have made this study prone to the specific choices of the researchers. Nevertheless, this study can be seen as a step forward toward a better understanding of the nature of innovation combined with complexity. From a research and theory perspective, this study has shown how theoretical models could offer real guidance to practicing organizations in addressing complex problems, particularly when using a combination of theories, rather than one model individually. More studies in the future may use this route to strengthen the link between theory and practice.

References

Abernathy, W. J., & Utterback, J. M. (1978). Patterns of industrial innovation. *Technology Review*, *80*(7), 40–47.

Altfeld, H. H. (2010). *Commercial aircraft projects: Managing the development of highly complex products*. Farnham, England: Ashgate.

Baker, W. E., & Sinkula, J. M. (2007). Does market orientation facilitate balanced innovation programs? An organizational learning perspective. *Journal of Product Innovation Management*, *24*(4), 316–334.

Balachandra, R., & Friar, J. H. (1997). Factors for success in R&D project and new product innovation: A contextual framework. *IEEE Transactions on Engineering Management*, *44*, 276–287.

Baron, C., Esteban, P., Xue, R., Esteve, D., & Malbert, M. (2015). A method and tool to support the management of systems engineering projects. *Technology Innovation Management Review*, *5*(3), 18–28.

Benner, M. J., & Tushman, M. L. (2003). Exploitation, exploration, and process management: The productivity dilemma revisited. *Academy of Management Review*, *28*(2), 238–256.

Beringer, C., Jonas, D., & Gemünden, H. (2012). Establishing project portfolio management: An exploratory analysis of the influence of internal stakeholders' interactions. *Project Management Journal*, *43*(6), 16–32.

Biedenbach, T., & Müller, R. (2012). Absorptive, innovative and adaptive capabilities and their impact on project and project portfolio performance. *International Journal of Project Management*, *30*(5), 621–635.

Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., & Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework. *International Journal of Project Management*, *29*(6), 728–739.

Brady, T., & Söderlund, J. (2008). Projects in innovation, innovation in projects selected papers from the IRNOP VIII conference. *International Journal of Project Management*, *26*(5), 465–468.

Burgelman, R. A. (1983). A process model of internal corporate venturing in the diversified major firm. *Administrative Science Quarterly*, *28*, 223–244.

Burns, T., & Stalker, G. (1961). *The management of innovation*. London, England: Tavistock.

Chao, R. O., & Kavadias, S. (2008). A theoretical framework for managing the new product development portfolio: When and how to use strategic buckets. *Management Science*, *54*(5), 907–921.

Chen, Y. J. (2015). The role of reward systems in product innovations: An examination of new product development projects. *Project Management Journal*, *46*(3), 36–48.

Chesbrough, H. W. (2006). The era of open innovation. *Managing Innovation and Change*, *127*(3), 34–41.

Cohan, P. (2009). Boeing's 787 Dreamliner faces another nightmare engineering delay. *Daily Finance*. Retrieved from http://www.dailyfinance.com/2009/11/13/boeings-787-dreamliner-faces-another-nightmare-engineering-dela/

Danneels, E. (2002). The dynamics of product innovation and firm competences. *Strategic Management Journal*, *23*(12), 1095–1121.

Davies, A., & Mackenzie, I. (2012). Project complexity and systems integration: Constructing the London 2012 Olympics and Paralympics Games. *International Journal of Project Management*, *32*(5), 773–790.

De Brentani, U., & Kleinschmidt, E. J. (2015). The impact of company resources and capabilities on global new product program performance. *Project Management Journal*, *46*(1), 12–29.

Dewar, R. D., & Dutton, J. E. (1986). The adoption of radical and incremental innovations: An empirical analysis. *Management Science*, *32*, 1422–1433.

Domke, B. (2008). Boeing 787 lessons learnt. EIXDI—Ref. PR0813399 (Issue 2). Retrieved from http://www.planebusiness.com/buzz/airbus2.pdf

Drazin, R., & Van de Ven, A. H. (1985). Alternative forms of fit in contingency theory. *Administrative Science Quarterly*, *30*, 514–539.

Franck, C., Lewis, I. A., & Udis, B. (2009). *New patterns of collaboration and rivalry in the U.S. and European defense and aerospace industries*. Monterey, CA: Naval Postgraduate School. Retrieved from http://hdl.handle.net/10945/615

Frankelius, P. (2009). Questioning two myths in innovation literature. *Journal of High Technology Management Research*, *20*(1), 40–51.

Galbraith, J. R. (1982). Designing the innovating organization. *Organizational Dynamics*, *10*(3), 5–25.

Gann, D. M., & Salter, A. J. (2000). Innovation in project-based, service-enhanced firms: The construction of complex products and systems. *Research Policy*, *29*(7), 955–972.

Garcia, R., & Calantone, R. (2002). A critical look at technological innovation typology and innovativeness terminology: A literature review. *Journal of Product Innovation Management*, *19*(2), 110–132.

Gates, D. (2008, December 1). Boeing 787 fastener problems caused by Boeing engineers. *The Seattle Times.*

Gatignon, H., Tushman, M. L., Smith, W., & Anderson, P. (2002). A structural approach to assessing innovation: Construct development of innovation locus, type, and characteristics. *Management Science*, *48*(9), 1103–1122.

Gemünden, H. G., Salomo, S., & Hölzle, K. (2007). Role models for radical innovations in times of open innovation. *Creativity and Innovation Management*, *16*(4), 408–421.

Geraldi, J., Maylor, H., & Williams, T. (2011). Now, let's make it really complex (complicated) a systematic review of the complexities of projects. *International Journal of Operations & Production Management*, *31*(9), 966–990.

Germain, R. (1996). The role of context and structure in radical and incremental logistics innovation adoption. *Journal of Business Research*, *35*(2), 117–127.

Hanisch, B., & Wald, A. (2012). A bibliometric view on the use of contingency theory in project management research. *Project Management Journal*, *43*(3), 4–23.

Henderson, R. M., & Clark, K. B. (1990). Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly*, *35*, 9–30.

Hobday, M., & Rush, H. (1999). Technology management in complex product systems (CoPS): Ten questions answered. *International Journal of Technology Management*, *17*(6), 618–638.

Holmes, S. (2006, June 19). The 787 encounters turbulence: Technical glitches and manufacturing woes could delay Boeing's breakthrough. *Business Week online*, pp. 38–40.

Howell, D., Windahl, C., & Seidel, R. (2010). A project contingency framework based on uncertainty and its consequences. *International Journal of Project Management*, *28*(3), 256–264.

James, A. (2009, April 30). Boeing's 787 production is mission-controlled. *Seattlepi*. Retrieved from http://www

.seattlepi.com/business/405751_boeing29.html

Killen, C. P., Hunt, R. A., & Kleinschmidt, E. J. (2008). Project portfolio management for product innovation. *International Journal of Quality & Reliability Management*, *25*(1), 24–38.

Kock, A., Gemünden, H. G., Salomo, S., & Schultz, C. (2011). The mixed blessings of technological innovativeness for the commercial success of new products. *Journal of Product Innovation Management*, *28*(Suppl. 1), 28–43.

Kock, A., Heising, W., & Gemünden, H. G. (2014). How ideation portfolio management influences front-end success. *Journal of Product Innovation Management*, *32*(4), 539–555.

Komonews.com (2015). A timeline of Boeing's 787 Dreamliner. Retrieved from http://komonews.com/archive/a-timeline-of-boeings-787-dreamliner

Kotha, S., & Srikanth, K. (2013). Managing a global partnership model: Lessons from the Boeing 787 "Dreamliner" program. *Global Strategy Journal*, *3*(1), 41–66.

Leifer, R., McDermott, C. M., O'Connor, G. C., Peters, L. S., Rice, M. P., & Veryzer, R. W. (2000). *Radical innovation: How mature companies can outsmart upstarts*. Boston, MA: Harvard Business School Press.

Lenfle, S. (2008). Exploration and project management. *International Journal of Project Management*, *26*(5), 469–478.

Lenfle, M., & Midler, C. (2009). The launch of innovative product related services: Lessons from automotive telematics. *Research Policy*, *38*(1), 156–169.

Lundin, R. A., & Söderholm, A. (1995). A theory of the temporary organization. *Scandinavian Journal of Management*, *11*(4), 437–455.

Lunsford, J. L., & Glader, P. (2007, June 19). Boeing's nuts-and-bolts problem: Shortage of fasteners tests ability to finish Dreamliner. *Wall Street Journal*.

MacPherson, A., & Pritchard, D. (2005). *Boeing's diffusion of commercial aircraft design and manufacturing technology to Japan: Surrendering the U.S. aircraft industry for foreign financial support*, (Canada-United States Trade Center Occasional Paper No. 30). New York, NY: State University of New York.

March, J. G. (1991). Exploration and exploitation in organizational learning. *Organization Science*, *2*(1), 71–87.

Marquis, D. (1969). The anatomy of successful innovations. *Innovation Newsletter*, *1*(7), 29–37.

McInnes, I. (2008). A 787 supply chain nightmare. *Aerospace-technology.com*, Retrieved from http://www.aerospace-technology.com/features/feature1690/

Mecham, M. (2011, September 26). 787: The century's first jet to fly; 787's impact will likely be remembered long after its tardiness is forgotten. *Aviation Week & Space Technology*.

Meifort, A. (2015). Innovation portfolio management: A synthesis and research agenda. *Creativity and Innovation Management*. doi:10.1111/caim.12109

Norris, G., & Wagner, M. (2009). *Boeing 787 Dreamliner*. Minneapolis, MN: Zenith Press, MBI Publishing Company.

O'Connor, G. C. (2008). Major innovation as a dynamic capability: A systems approach. *Journal of Product Innovation Management*, *25*(4), 313–330.

O'Connor, G. C., & Rice, M. P. (2013). New market creation for breakthrough innovations: Enabling and constraining mechanisms. *Journal of Product Innovation Management*, *30*(2), 209–227.

OECD. (2005). *Proposed guidelines for collecting and interpreting technological innovation data. Oslo manual* (3rd edition). Paris, France: Author.

Payne, H. J., & Turner, R. J. (1999). Company-wide project management: The planning and control of programmes of projects of different type. *International Journal of Project Management*, *17*(1), 55–59.

Pennings, J. M. (1992). Structural contingency theory: A reappraisal. *Research in Organizational Behavior*, *14*, 267–309.

Perrow, C. C. (1967). A framework for the comparative analysis of organizations. *American Sociological Review*, *32*, 194–208.

Pich, M. T., Loch, C. H., & De Meyer, A. (2002). On uncertainty ambiguity and complexity in project management. *Management Science*, *48*(8), 1008–1023.

Project Management Institute (PMI). (2013). *A guide to the project management body of knowledge (PMBOK® guide)*– Fifth edition. Newtown Square, PA: Author.

Ritter, T., & Gemünden, H. G. (2003). Network competence: Its impact on innovation success and its antecedents. *Journal of Business Research*, *56*(9), 745–755.

Salomo, S., Weise, J., & Gemünden, H. G. (2007). NPD planning activities and innovation performance: The mediating role of process management and the moderating effect of product innovativeness. *Journal of Product Innovation Management*, *24*(4), 285–302.

Saren, M. A. (1984). A classification and review of models of the intra-firm innovation process. *R&D Management*, *14*(1), 11–24.

Shenhar, A. J. (2001). One size does not fit all projects: Exploring classical contingency domains. *Management Science*, *47*(3), 379–414.

Shenhar, A. J., & Dvir, D. (2004, July). *Project management evolution: Past history and future research directions*. PMI® research conference proceedings, PMP, Vol. 2, London, England.

Shenhar, A. J., & Dvir, D. (2007). *Reinventing project management: The diamond approach to successful growth and innovation*. Boston, MA: Harvard Business Press.

Sicotte, H., Drouin, N., & Delerue, H. (2014). Innovation portfolio management as a subset of dynamic capabilities: Measurement and impact on innovative performance. *Project Management Journal*, *45*(6), 58–72.

Tang, C. S., Zimmerman, J. D., Nelson, M. S., & James, I. (2009). Managing new product development and supply chain risks: The Boeing 787 case. *Supply Chain Forum: An International Journal, 10*(2), 74–86.

Tepic, M., Kemp, R., Omta, O., & Fortuin, F. (2013). Complexities in innovation management in companies from the European industry. *European Journal of Innovation Management, 16*(4), 517–550.

Teresko, J. (2007). The Boeing 787: A matter of materials. Special report: Anatomy of a supply chain. *Industry Week*. Retrieved from http://www.industryweek.com/forward/emailref?path=node/12343

***The Seattle Times*. (2009, December 15).** Building the 787 Dreamliner: A timeline. Retrieved from http://seattletimes.nwsource.com/html/boeingaerospace/2010509566_787timeline15.html

Thompson, J. D. (1967). *Organizations in action*. New York, NY: McGraw-Hill.

Tishler, A., Dvir, D., Shenhar, A., & Lipovetsky, S. (1996). Identifying critical success factors in defense development projects: A multivariate analysis. *Technological Forecasting and Social Change, 51*(2), 151–171.

Trimble, S. (2007, September 10). Boeing 787 first flight suffers two-month delay. *Flight International*. Retrieved from http://www.flightglobal.com/news/articles/boeing-787-first-flight-suffers-two-month-delay-216664/

Turner, J. R., & Cochrane, R. A. (1993). Goals-and-methods matrix: Coping with projects with ill defined goals and/or methods of achieving them. *International Journal of Project Management, 11*(2), 93–102.

Unger, B. N., Rank, J., & Gemünden, H. G. (2014). Corporate innovation culture and dimensions of project portfolio success: The moderating role of national culture. *Project Management Journal, 45*(6), 38–57.

Useem, M. (2006). How well-run boards make decisions. *Harvard Business Review, 84*(11), 130–138.

Wheelwright, S. C., & Clark, K. B. (1992, March–April). *Creating project plans to focus product development*. Cambridge, MA: Harvard Business School Publishing.

Williams, T. (1999). The need for new paradigms for complex projects. *International Journal of Project Management, 17*(5), 269–273.

Ye, L., Lu, Y., Su, Z., & Meng, G. (2005). Functionalized composite structures for new generation airframes: A review. *Composites Science and Technology, 65*, 1436–1446.

Youker, R. (2002). *The difference between different types of projects*. PMI® 30th Annual Seminar Symposium, 2002 Philadelphia, PA, USA.

Aaron J. Shenhar, PMI Fellow, is a Professor of Project Management and Leadership at Tel-Aviv University, Israel, and the CEO of SPL, an education and consulting organization dedicated to aligning projects and business. Until 2008 he was Institute Professor of Management and the founder of the project management program at Stevens Institute of Technology. Previously he held various positions at the Universities of Minnesota and Rutgers Business School. He holds five academic degrees in engineering and management from Stanford University and the Technion in Haifa, Israel. He was the first recipient of the Project Management Institute Research Achievement Award, recipient of the IEEE Engineering Manager of the Year Award and was recently awarded as PMI Fellow as well as the IMPA Research Achievement Award.
With over 80 refereed research articles, his research was published in journals such as *Strategic Management Journal, Management Science, Sloan Management Review, Research Policy*, and *IEEE Transactions on Engineering Management*. He also served as consultant to major companies such as Intel, 3M, Honeywell, NASA, and IAI, as well as the aerospace industry in its Program Excellence Award. He can be contacted at aaron.shenhar@gmail.com2

Vered Holzmann earned her PhD degree in management from Tel-Aviv University for her dissertation on "A Model for Risk Management Based on Content and Clustering Analyses." She has graduated with honors from the Department of Philosophy (BA) and graduated from the School of Business, Tel-Aviv University, with a thesis on the subject of communications effectiveness in projects (MBA). Vered is a seasoned project manager (PMP, SCM) with a distinguished record of accomplishment in managing international projects in higher education, leading software development teams, and supervising quality assurance and control of fast track projects. Serving as the VP for research and academic affairs in the PMI Israel Chapter, Vered is responsible for initiation and organization of academic conferences, awarding scholarships, and managing the academic forum. Vered serves as a lecturer in the faculty of management in Tel-Aviv University, and her research interests include communications and knowledge management, internationalization, project risk management, and entrepreneurship and innovation in the context of leadership and management. She can be contacted at veredhz@post.tau.ac.il

---

Benjamin Melamed is a Distinguished Professor in the Department of Supply Chain Management, Rutgers Business School—Newark and New Brunswick, Rutgers University, New Jersey, USA. He has a PhD and MSc in Computer and Communications Sciences, from University of Michigan, Ann Arbor, and a BSc, in Mathematics and Statistics, from Tel-Aviv University, Israel. Before joining Rutgers he was a department head at NEC USA Inc., and a member of the technical staff at AT&T Bell Labs. Melamed's research interests include supply/service chain operational and financial management (including modeling, analysis, simulation and optimization), systems modeling and performance evaluation, stochastic processes, traditional and hybrid simulation (discrete-event and fluid-flow paradigms), and decision support tools. He authored or co-authored over 100 papers and co-authored two books, and has published in a broad range of scientific journals, including *Operations Research, Mathematics of Operations Research, Management Science, J. of Applied Probability, Advances in Applied Probability, J. of Stochastic Processes and their Applications, IEEE Trans. on Automatic Control, Annals of Operations Research, Stochastic Models, Journal of Business Logistics, Performance Evaluation, J. of Optimization Theory* *and Applications, Nonlinear Analysis, JACM and QUESTA*. He performed studies for NJ-DOT, DHS, NSF, and DARPA. Melamed was awarded an AT&T Fellow in 1988 and an IEEE Fellow in 1994. He can be contacted at melamed@rutgers.edu

Yao Zhao is a Professor in the Department of Supply Chain Management, Rutgers Business School—Newark and New Brunswick, Rutgers University, New Jersey. He holds a PhD degree in Industrial Engineering and Management Sciences from Northwestern University, Evanston, Illinois, USA. He is the co-director of the Rutgers Supply Chain Analytics Laboratory and a faculty fellow at the Lerner Center for Pharmaceutical Management Studies at Rutgers. He was a visiting scholar at Duke Fuqua School of Business and MIT Operations Research Center. His research interests lie in supply chain management, project management, and healthcare services management. He has published in leading operations research and management journals such as *Operations Research, Manufacturing & Service Operations Management (M&SOM), Production and Operations Management*, and serves as an associate editor for *Operations Research*. He is the recipient of an honorable mention in the M&SOM student paper competition in 2001, the National Science Foundation Career Award in Manufacturing Enterprise Systems in 2008, the Dean's Award for Meritorious Research in 2011, and the first prize in the INFORM case writing competition in 2014. He can be contacted at yaozhao@andromeda.rutgers.edu