AN INTEGRATED STRATEGIC SOURCING PROCESS FOR COMPLEX SYSTEMS

by

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Submitted to the MIT Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
and
Master of Science in Engineering Systems

In conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2009

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ABSTRACT

Aerospace firms continue to outsource increasingly complex components and systems for access to talent, lower costs, and global presence. In addition to strong competition from Airbus and other emergent companies, Boeing is faced with the challenge of reducing financial risk and placing work internationally to offset foreign sales obligations. The organization has recognized a need for an integrated framework to consistently make sourcing decisions that limits subjectivity and positions the company for continued success.

This thesis is based on a six-month internship study with the Future Production System team based in Seattle, WA and it examines the strategic sourcing decision process at Boeing Commercial Airplanes. A discussion-based strategic sourcing process utilizing a holistic range of factors is proposed to test whether an expensive, complex, and integrated system like a composite airplane wing should be outsourced or if it should be designed and produced internally.

This workshop-based strategy development process develops weighted factors through a structured, cross-functional process where multiple proposals can be evaluated based on their performance against a set of quantitative and qualitative factors such as cost, quality, flow, knowledge management, stability, and risk. The development of a baseline sourcing proposal for a composite airplane wing demonstrated the process. Careful assumptions were made and data collected to ensure a realistic scenario for a future single-aisle plane. The documented baseline wing sourcing strategy includes recommendations for proximity, design integration, and production responsibilities.

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ACKNOWLEDGMENTS

I would like to thank Boeing for sponsoring this internship. It has been a great experience where I have built relationships, furthered my appreciation for the industry, and had an opportunity to see the inner workings of the commercial airplane business. In particular, the Future Production System team has been very generous and helpful in welcoming me onto their team. Thank you Jon Geiger for being such a supportive sponsor and for providing the resources for this project. A special thanks goes to Isaac Jacob for sharing his friendship, time, and knowledge.

There are too many others to list in all, but I would also like to express my gratitude to the following individuals at Boeing: Peter Anast, Mike Blanchard, Lindsey Douglas, Steve Kirchmeier, Karl Kunst, David Leonhardi, Rohit Matthew, Ben McCullough, Doug McLaren, Victor Mroczkowski, Ren Nanstad, Russ Nash, Sandy Postel, Stephanie Ruiz, Mario Villa, and David Wirth.

I would also like to thank my two advisors, Don Rosenfield and Daniel Whitney. I am lucky to be the beneficiary of their deep insight and wealth of experiences. They have been invaluable to shaping my thought process and providing valuable (and much needed) feedback on my thesis. They have not only pushed me to think harder about issues facing companies, they have opened me to a world of leading thought.

Thank you Leaders for Global Operations (formerly Leaders for Manufacturing) program for providing the experience of a lifetime - an experience that could not have been as fun, educational, and fulfilling if not for my great classmates.

I would like to thank my parents for always believing in me. They have encouraged me to follow my passions and let me make my own decisions (and mistakes). Without their love, lessons, and freedom, I would not be who I am today.

Last and most important, I'd like to whole-heartedly thank my wife, Yu-chia, for her never-ending love and support. She has unconditionally been by my side and has sacrificed so much so that we can go through this experience together. No matter where we have been, she has always made our home, sweet home. I am so grateful to have such a special life partner.

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1 Introduction

Outsourcing and global sourcing have increasingly become the prescription for how to increase corporate profits and free up resources to focus on the higher-value segments of the value chain. Many companies have extended their supply chain in order to take advantage of these hoped-for benefits.

In some cases, outsourcing decisions do not fully consider all the relevant long-term factors and risks. This thesis follows up the Mroczkowski (2008) study at Boeing Commercial Airplanes (BCA) and explores the sourcing decision process in additional depth. A discussion-based approach is proposed and the process is demonstrated with a case: the design and build sourcing proposal for a composite airplane wing. This study considers multiple factors to recommend a sourcing proposal for the wing.

1.1 Statement of Problem

Boeing Commercial Airplanes faces increasing challenges in striking the right balance of maintaining internal capabilities, accessing global talent, managing extended enterprise capacity, placing work globally for market access, and minimizing cost and risk. These complex strategic and quantitative factors necessitate a structured method of making important vertical integration decisions.

Boeing has traditionally maintained control of wing production. The 787 Program is the first Boeing-designed airplane where the wing production was outsourced. Mitsubishi Heavy Industries (MHI), a long-time Boeing supplier, joined the design team at the concept phase and collaboratively designed and then produced the wing. This coincides with the switch to composite materials. While there are similarities to the 777 composite horizontal stabilizers and 777/787 vertical tail fins that Boeing currently builds, Boeing does not produce any composite airplane wings. It will be important to understand whether Boeing should retain the capacity and capability on their next new airplane.

To be most effective, Boeing's sourcing process must utilize all of its stakeholders and tools to source in an integrated, objective, and repeatable manner to enhance Boeing's best long-term interests. For Boeing to be sustainable in the long-term, sourcing decisions must be made to balance short-term profits with the creation of additional value-adding capabilities. This thesis suggests that the sourcing of complex products should use a structured process to consider a wide range of factors.

1.2 Purpose of Study

This research proposes a process and certain key criteria to use as the basis for making strategic sourcing decisions. This method is demonstrated with the case of a future composite airplane wing. There are limits to the application and recommendations. The specific recommendations are based on a single scenario with a fixed set of assumptions. The business and competitive landscape may change and assumptions may or may not hold true. This sourcing process considers the long-term competitive position and stakeholders such as employees, suppliers, and customers.

The goals of the project are two-fold. The primary goal is to demonstrate an integrated, transparent, and repeatable strategic sourcing process for making important vertical integration and sourcing decisions. It should enable an informed consensus while creating the awareness necessary to plan for risks. It utilizes the decision dialogue process to determine weighted criteria and explore strategies for the implementation of a potential single-aisle airplane composite main wing box into the supply stream.

The second goal is to create a composite wing design and production sourcing proposal to act as the baseline for making this potential future decision. It provides a structure for the future proposal and consolidates many of the factors and information that should be considered in making this decision.

1.3 Approach & Methodology

The primary sources of information include interviews with multiple functions and levels within the organization, plant visits, attendance at sourcing meetings and workshops, technical meetings, company data, academic literature, and various publications. Most importantly, internal interviews were conducted to gain a better understanding of the challenges faced with sourcing complex systems. The overall approach was to identify the problem, research existing studies and frameworks, and to propose and test an idealized approach for Boeing.

The six sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology was used as a framework for the overall process steps. The DMAIC steps were used to generate deliverables and visualize the overall process. The problem was defined, the current state was understood and measured, processes and sourcing considerations were analyzed, improvements and recommendations were made, and then this output will be controlled through other deliverables including this thesis.

1.4 Thesis Roadmap

This thesis begins by setting the context of the airplane manufacturing industry and Boeing Commercial Airplanes. Then, supply chain considerations relating to outsourcing, supplier relationships, and the enterprise are discussed. Factors pertaining to vertical integration and composites usage in airplanes are described preceding discussion of the make-buy decision and the sourcing process at Boeing Commercial Airplanes. Then, a discussion-based sourcing process is proposed and a composite airplane wing case study is presented which leads to production recommendations for this airplane wing scenario.

2 Background and Sourcing Context

2.1 Airplane Manufacturers and the Airline Industry

The aerospace industry is dominated by several large companies manufacturing airplane, defense, and space products. The top airplane manufacturers include Boeing, Airbus, Embraer, and Bombardier. All four are private companies although one could argue that they all have a degree of government influence. There has been increasing competition for aerospace work as the industry brings high-paying jobs and prestige. Countries around the world are increasingly cultivating their domestic aerospace industries. Some notable examples are China, Japan, UK, Russia, and Abu Dhabi.

As airplane outsourcing shifts production from established aerospace manufacturing hubs to new locations and workforce reductions are enabled by automation and productivity improvements, there is growing labor unrest. While Boeing was able to avert a strike with the Society of Professional Engineering Employees in Aerospace (SPEEA) union, the International Association of Machinists (IAM) union went on strike. One of the primary disagreements that led to the 2008 Boeing IAM strike was outsourcing. Despite the faltering world economy, the strike lasted for 58 days as the two sides negotiated over job security and manufacturing flexibility (Lunsford, Outsourcing at Crux of Boeing Strike, 2008).

Two of Boeing's largest customers, International Lease Finance Corporation (ILFC) of AIG and GE Commercial Aviation Services (GECAS) of General Electric, are aircraft finance units that lease aircraft to airlines. Both units are being negatively impacted by financial troubles at their parent companies. In addition, airlines needing loans to buy planes are facing difficulties stemming from the financial crisis. The cost and availability of capital are both being negatively impacted. To compensate, top executives at Boeing and Airbus have stated that they are willing to increase lending programs if necessary (Rothman, 2008). If airplane orders do not resume or airlines cannot pay for their orders, production cuts or the building of whitetails may ensue. Although Boeing has a current backlog of airplane orders, they have announced 777 production cuts in 2010 and the delay of production increases for the 747 and 767 programs (Mecham, 2009).

During one week in April 2008, three US carriers: Aloha, ATA, and Skybus Airlines declared bankruptcy (CNN, 2008). In addition, there has been ongoing consolidation with Lufthansa buying stakes in Austrian Air and Brussels, The Delta-Northwest Merger, and Air France-KLM's purchase of Alitalia. The lack of credit is also affecting suppliers. Due to difficulty in securing financing, some OEM's and Tier 1 suppliers are forced to find solutions to keep their smaller suppliers' operations running. Some observers believe that a portion of the supply base is at risk (Anselmo & Mecham, 2008).

2.2 Aerospace Industry Supply Base

There is a large number of suppliers in the aerospace industry. As of a few years ago, Boeing had 15,000 suppliers based in 81 countries (Koellner, 2002). This collection of suppliers provides a vast number of parts to The Boeing Company. Just one Boeing 777 contains over 3 million parts, of which an estimated 120,000 are unique (design4x, 2008). However, following faster clockspeed industries like the auto industry, the aerospace and defense supply base is consolidating as the OEMs strengthen their relationships with fewer numbers of suppliers and shift more integration responsibilities to suppliers. Embraer had four risk-sharing partners and 350 suppliers to develop small regional jets a decade ago. Now, the company has 16 risk-sharing partners and only 22 suppliers on the larger 170/190 program (Wallace, Sharing the Risk for 7E7, 2003).

The aerospace supply base has historically been of a build-to-print model where the manufacturer specifies the design and process to the supplier. More recent programs like the 787 have transferred additional responsibility to the supply base. The added responsibilities require suppliers to develop additional engineering integration, program management, and supply chain expertise. While each supplier is at a different level of capability, expertise in these areas has been growing throughout the supply base, particularly among tier 1 suppliers. For example, Spirit Aerosystems, created in 2005, was once a division of Boeing.

As the financial crisis deepens, OEM's and suppliers face a challenging downturn. Supplier consolidation may accelerate with financially-troubled suppliers going out of business or being acquired.

2.3 The Boeing Company

The Boeing Company (NYSE: BA) is the world's largest manufacturer of commercial jetliners and military aircraft.

- Revenue: $60.9 billion USD (2008)[1]
- Headquarters in Chicago, Illinois
- 160,932 employees across the United States and in 70 countries[2]

Founded in 1916, The Boeing Company has grown to become the world's largest, most diversified aerospace company.[3] The company is evenly split between Commercial Airplanes (BCA) and Integrated Defense Systems (IDS). Boeing designs and manufactures commercial aircraft, rotorcraft, electronic and defense systems, missiles, satellites, launch vehicles and advanced information and communication systems. The company sells products and services to over 90 countries and holds the distinction of being the United States' largest exporter.

Following World War II, Boeing solidified market dominance in the commercial aircraft industry. Prior to Boeing's merger with McDonnell-Douglas in 1997, Boeing's commercial airplane business was the world's largest. At the time, it comprised approximately 80% of the company's revenue (Lunsford, Navigating Change, 2003).

Boeing Capital Corporation (BCC), the Shared Services Group (SSG), and Phantom Works support BCA and IDS. BCC provides financing solution to deliver Boeing products, SSG provides infrastructure services (like facilities, security, transportation, etc.), and Phantom Works conducts advanced research and development.

[1] As reported in The Boeing Company 2008 Annual Report.

[2] As of March 31, 2009 (http://www.boeing.com/employment/employment_table.html).

[3] Former aerospace companies now part of the Boeing enterprise include: North American Aviation/Rockwell International (1996), McDonnell Douglas (1997), Hughes Space & Communications (2000), Jeppesen Sanderson (2000), and Hawker de Havilland (2000).

2.4 Boeing Commercial Airplanes

Boeing Commercial Airplanes is the commercial aviation division of The Boeing Company that accounts for approximately half of the total company revenue.

- Revenue: $28.3 billion USD (2008)[4]
- Headquarters in Renton, Washington
- 66,909 employees[5]

In 1998, Phil Condit, former Chairman and CEO, created the Vision 2016 statement. As part of this vision, Boeing would take the role of a Large Scale Systems Integrator. This would move the company away from fabricating and manufacturing the majority of airplane components. To fulfill this vision, Boeing began a series of divestments of many of its fabrication divisions (See Appendix 2) and seized the role of systems integrator on the 787 airplane program.

In December 2008, the division was reorganized to combine all airplane programs into a single Airplane Programs organization. A new Supply Chain Management and Operations team was created at the same time. The Commercial Aviation Services (CAS) business unit remains unchanged.[6]

Airplane Programs currently produces passenger airplanes and freighters built off of five distinct aircraft families: the 737, 747, 767, 777, and 787 (see Appendix 1 for photos of current and discontinued aircraft). In development are the 787 program and the 747-8, a larger, more fuel efficient version of the 747. The 737 is produced on two production lines in Renton, WA. All other airplane programs are produced on individual production lines in Everett, WA.

- **The 787 Dreamliner** is the world's first mostly composite commercial airplane family. Launched in April 2004, the fuel-efficient airplane program has been delayed due to engineering and supply chain challenges. Entry into service is expected in 2010. Despite those challenges, the 787 is viewed as the most successful commercial airplane sales

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[4] As reported in The Boeing Company 2008 Annual Report.

[5] As of March 31, 2009 (http://www.boeing.com/employment/employment_table.html).

[6] The division was previously organized into three primary business units: 787 program, Commercial Aviation Services (CAS), and Airplane Programs (AP) which contains all non-787 programs.

campaign ever[7]. Partner suppliers have been asked to take on significantly more responsibility than ever before for managing the extended supply chain.

Supply Chain Management and Operations is a newly organized business unit that aligns the existing Supplier Management, Fabrication, Manufacturing & Quality, and Propulsion Systems organizations.

- **Supplier Management** buys the components and services required to build a Boeing airplane. The Seattle, Washington-based organization is responsible for the management of the supply base and for procurement of materials used to build the airplanes.
- **Fabrication Division** provides internally-produced components and services. This largest supplier to Boeing has manufacturing operations in Auburn, Frederickson and Everett, Wash.; Portland, Ore.; Salt Lake City, Utah; Oak Ridge, Tenn.; Winnipeg, Canada; as well as Fisherman's Bend (Melbourne) and Bankstown (Sydney), Australia. Those locations are responsible for delivery and integration of work that requires complex, critical, emergent and unique specialty production focused on precision machining, electrical and interior systems, and advanced primary and secondary composite structures.

Commercial Aviation Services (CAS), based in Seattle, Washington, operates the industry's largest field service organization. It offers support products and services to the BCA global customer base utilizing its capabilities in customer support, material management, maintenance and engineering services, fleet enhancements and modifications, and flight operations support. CAS provides spares, training, maintenance documents, and technical advice providing integrated solutions, products and services.

Boeing provides additional services to complement the airplane ownership and operating experience. These services include flight training through the Alteon division, Global Customer Support, Airplane Health Management, and Flight Operations Support, Integrated Materials Management, and Engineering Maintenance planning and control.

(Boeing Commercial Airplanes, 2007)

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[7] As of March 31, 2009, Boeing had 878 orders for the 787 from 55 identified customers in 36 countries.

2.5 Lessons Learned from the 787

Boeing took several ambitious steps to create a leading airplane in the 787. In many respects Boeing has been successful. Through the application of multiple improvements throughout the airplane, Boeing has been able to create customer value in the form of increased fuel efficiency and a premium passenger experience. The technology to enable composites fabrication is being commercialized. Sales quickly exceeded expectations and the backlog has grown to over 800 planes (Boeing, 2009).

However, Boeing simultaneously made a number of changes that stressed its ability to effectively execute on its plan. These include, for example, a step change increase in outsourcing, significant increase in usage of composite material, new composite manufacturing technologies, a new supply chain architecture, increased supplier responsibilities and financial risk-sharing agreements, a shortened development cycle, new computing processes and tools, and a new organizational model. Changes reduce stability and too many changes at once can overwhelm the capacity of resources to handle change. The large number of changing variables makes it difficult to distinguish between challenges resulting from a flawed strategy or unsatisfactory execution. Intel uses a method they refer to as "tick-tock" to deliver ongoing innovation. They alternate the implementation of new silicon technology and processor microarchitecture each year to manage the degree of change and maintain stability in their process (Intel Corporation).

Integral product architecture means that components and systems are designed to fit with each other and often perform multiple functions. This type of architecture is often used to increase performance. Integral products often require additional product iterations because of tighter interactions between components. This makes it difficult to reduce the development time for a highly integral product as specifications for structures and systems continually evolve. Boeing attempted to bring the 787 and its innovations to market in just over four years. If the program were to launch on time, this aggressive timeline would have been two years faster than any prior project (Lunsford, Jet Blues, 2007). However, program delays may prove costly. One reason is that airlines often seek compensation for losses and disruptions linked to aircraft delivery delays (Rothfeder, 2009).

Another important lesson is to maintain process discipline. Pressure to maintain the 787 launch schedule may have led to occasional choices inconsistent with Boeing's strong lean philosophy. After the July 8, 2007 rollout (07–08 -2007), it became known that there was travelled work on the first aircraft that still needed to be completed. This travelled work caused additional delays as many components were now being installed in Everett, WA as opposed to being pre-stuffed prior to shipment from the supplier. Mike Bair, the original executive responsible for the 787 program, said that the final assembly process had been designed to bring together far fewer parts than required for the first airplane. In addition to the added complexity, some of those parts arrived with insufficient documentation (Lunsford, Jet Blues, 2007). All stages of airplane programs are under significant time pressure which is combined with the industry's evolving business model of increased participation for design and build assigned to key partners. These factors will make it important to adhere to sourcing processes that utilize a balanced, long-term view.

Boeing also learned it must proactively strive and prepare for overall system success. They aligned incentives with supplier superintegrators who shared in the risks with Boeing. For example, some would not be paid until the first airplane was delivered. Since many of these suppliers were accustomed to their role in a build to print model, where the OEM does the development and provides a mostly-completed design and manufacturing plan to the supplier, their project management capabilities were not as developed as Boeing's abilities. These capabilities include sourcing expertise, a stage gate development process, parts tracking processes, and supplier qualification knowledge. These supplier superintegrators turned to other companies to complete much of this work – in some cases overburdening the same sub-tier supplier. It later became apparent that supplier superintegrators did not have the same degree of highly-evolved processes for validating their own supplier's work (Johnsson & Greising, 2007). Because of this, Boeing needed to provide more early support and track their sub-tier suppliers more closely. While Boeing designed the production system to reduce the expected flow time within their facility to three days per position (12 days in all), it is not clear if the total value chain flow time has increased due to suppliers pre-stuffing their sections before shipment.

The 787 program implemented Partner Managed Inventory (PMI). In this structure, Boeing purchases and owns some systems components while their major partners not only ship and receive parts, but manage those parts throughout the supply chain (including ordering, scheduling, receiving, non-conforming parts). Boeing creates blanket purchase orders. The benefits for Boeing are that they reduce their own supply chain management costs, partly through more partner-to-partner collaboration. A disadvantage is that it increases the impact of poor delivery performance, logistics costs, and complicates travelled work. Those systems are shipped to suppliers around the world, pre-stuffed into sections of the aircraft, and then shipped to Boeing's final assembly in Everett, WA. This increases opportunities for damage and increases the inventory holding costs by lengthening the time inventory must be held. Also, different supplier schedules drives variability into the production schedule for systems and eliminates inventory pooling effects that would reduce the required safety stock.

An additional lesson pertains to maintaining control of information that may be released by Boeing or its suppliers. Airbus created a detailed "Boeing 787 Lessons Learnt" document based on in depth insider information. This information included internal manufacturing data, product details, and test results. Airbus' report critiqued multiple aspects of the 787 Program from root causes for the delays as well as potential performance shortfalls. Airbus casts doubt on the ability of Boeing to deliver on publicly stated commitments (Domke, 2008). If true, timing delays and potential performance shortfalls means Boeing will likely incur penalties that are typically written into the airline purchase contracts.

At the time of this writing, Boeing awaits the first flight in the second quarter of 2009 and expects the first delivery in the first quarter of 2010 (787 Communications, 2008). It is too early to predict the final outcome and one can hope that Boeing learns these important lessons without swinging the pendulum back too far the other direction.

2.6 Three Lens Analysis

Decisions may be made with the subconscious aid of technical, economic, and political screens. This project was chosen to help BCA make better and more informed sourcing decisions. Decisions were often made in an inconsistent manner which did not consider all their impacts. This decision-making framework gives leadership a structured way to evaluate vertical integration decisions that will guide them to considering the most important factors. Also, it provides a consistent way to evaluate different proposals and presents the information in an easy to compare manner. The composite wing sourcing proposal provides valuable insight for the future design and production value stream. The wing sourcing proposal recommends crucial elements such as ownership of wing assembly and integration, location relative to final assembly, and design, certification, and test responsibilities. Implementing this proposed sourcing process may require some parts of Boeing's organization to change.

The three lens approach developed at MIT provided a structured framework to consider how to relate and interact with the organization to affect change (Ancona, Kochan, Scully, & Van Maa, 1999). Organizations are extremely complex and the three lenses approach provided a way to see the key dimensions of strategy, culture, and politics. It also provided insights into the interdependencies of each lens. In particular, the political and cultural lenses influenced how to approach strategic organization.

Strategic Design:

"A million parts flying in formation." This self-deprecating joke describes not only the airplane itself, but the high speed organization in place to design and build it. This statement captures the complexity in the product and organization, alignment in sharing a common focus (Thomas, 1994). Top BCA leadership buy-in is necessary for sustained organizational change.

The Boeing Future Production System (FPS) team was established to integrate lessons learned from Boeing and industry and develop a long term strategic plan for the Boeing global production system. The FPS team is part of the Supply Chain Management and Operations division and the team maintains close links to the product development, supplier management, and strategy teams through frequent meetings. They hold regular cross-functional meetings with leaders from across the organization.

This sourcing project is an enabler for some elements of the future production system. Sourcing decisions have an effect on where design and build occur, what types of suppliers and partners Boeing is working with, as well as the supply chain architecture and flow of parts. In order for outsider-insiders, internal employees with outside perspectives that can operationalize change, to affect change throughout the organization, new ways of going about sourcing must be aligned with Boeing's strategic and operational objectives. With continuing challenges on the 787 program, there seems to be recognition that the company cannot continue to operate with the same old behaviors.

Cultural:

Boeing has traditionally been an engineering-centric company. The company tends to prioritize airplane performance above manufacturability, cost, process discipline, and stability. They make an effort to create the best airplane which utilizes the latest technology available. This has enabled the company to create high-performing airplanes. While perceived performance may be better, the marketplace has voted with their orders; placing more value with the Airbus airplane ownership experience. In addition, Airbus boasts more consistent production, employment, and profitability. Boeing takes pride in making great airplanes and now has an increasing recognition that it must also compete on production capability, quality, and cost. This recognition is creating pull for change.

It is often said that Boeing "bets the company" on each new airplane program due to the large upfront development costs that can take years to recoup. In an effort to reduce this non-recurring investment and associated risk, Boeing chose to use multiple risk-sharing partners on the 787 program.

Some employees feel that outsourcing work is less costly than performing the same work internally. Some reasons for this are the higher compensation and benefits that Boeing employees earn. In addition, there are certain jobs and work rules that add additional cost for doing business with the IAM at Boeing. The assumption that Boeing-produced parts are more expensive is true based on traditional cost accounting where overhead is wrapped into the "standard rate" of a line worker, but this assumption is not necessarily true when Boeing utilizes existing capacity. Many of the overhead costs are fixed. For example, building and logistics costs do not change based on the number of hours worked by employees. Maintaining the same fixed costs with fewer employees, there will be a higher burden and "standard rate" for each hour of labor.

Fortunately, there is growing awareness of lean accounting and how it will help Boeing more accurately assess costs. Lean accounting uses value stream costing. Overhead allocation is not used in the decision-making process. Only direct and unique costs are included. Training is being rolled out throughout the organization and the fabrication division is using it to more accurately reflect the true costs. Chapter 4 discusses lean accounting in greater detail through the use of an example.

Global strategy, a department which allocates work to various countries, sees many of the same issues with sourcing as the FPS team. Production challenges have at times been aggravated by the placement of work with developing suppliers throughout the world. Global Strategy is in the process of redesigning one of the company's sourcing processes to better reflect the company's long-term needs. They have been receptive to collaboration. I have helped organize and run workshops while they have used a composite wing scenario.

Input was gathered from multiple organizations to understand their needs and show why the project can help make their lives better. Leadership and cross-functional stakeholder support is critical for the project's survival.

Political:

There are many organizations that are affected by sourcing decisions. Each organization has unique responsibilities and wields varying amounts of power. A sample of the most heavily involved organizations is described below.

The BCA Leadership team holds much of the cross-cutting functional responsibility that include the individual airplane programs and finance.

Supplier Management is responsible for the management of the supply base and for procurement of materials and services used to build the airplanes.

Global Strategy is responsible for industrial participation and facilitates the supply stream sourcing meetings.

The Boeing Production System (BPS) team drives lean manufacturing principles throughout the organization.

The Future Production System (FPS) team (now integrated in BPS) has been responsible for studies on the sourcing process in addition to other important projects.

The Fabrication Division is the single largest supplier for the airplane programs and has decreased in size due to divestures and layoffs. Its unionized IAM workforce focuses on the highest value-added and most complex machining and airplane final assembly.

A simplified stakeholder map focused around the sourcing process (See Figure 1) depicts some of the affected organizations. This diagram is meant to show relationships with the sourcing process and is not a representation of Boeing's organizational structure.

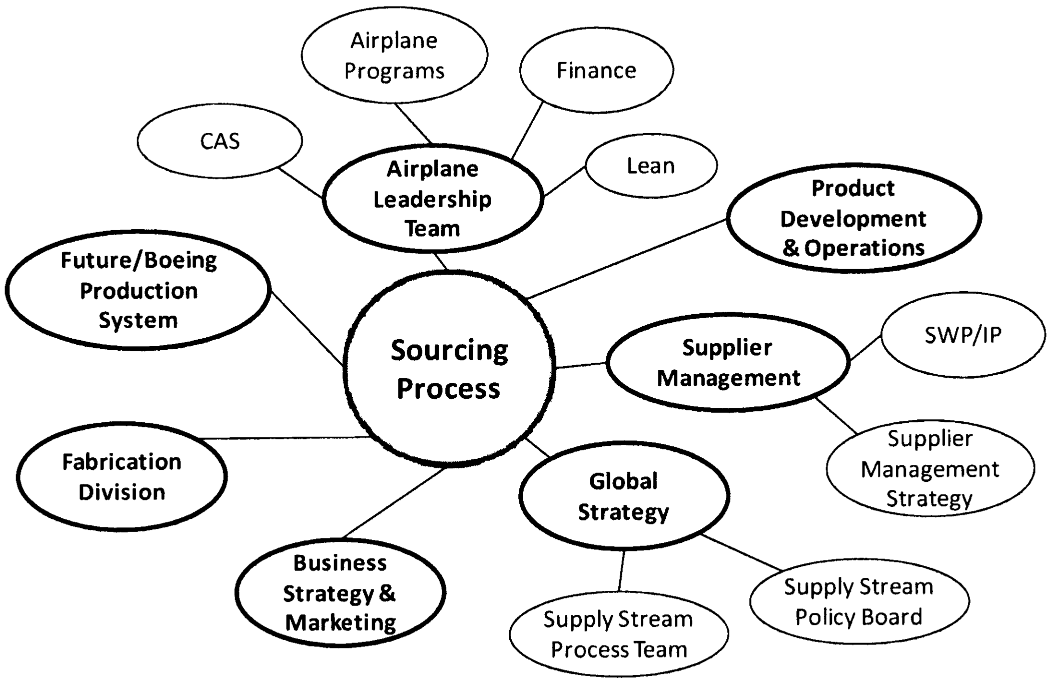

Figure 1: Sourcing Process Stakeholder Map (Mroczkowski, 2008)

Stakeholders hold conflicting desires as with any design, but their interests are compatible. Several groups would like to keep all production co-located in the Seattle area. Others want to distribute work globally to fully support foreign sales. A balance should be targeted to support a sustainable, successful enterprise. If global strategy and sales can work pro-actively with the rest of the organization, outsourcing can be planned in a less-disruptive manner.

The cross-functional Airplane Leadership team wields formal authority and power. Supplier Management controls supplier relationships, how the airplane is divided into work packages, and the sourcing decisions for many of those work packages. Product Development and Operations traditionally has less authority over sourcing decisions. If the sourcing process is standardized and/or work is vertically integrated, the balance of power will change. It will reduce supplier management's power and shift more of the responsibility to the Airplane Leadership and Global Strategy. Product Development and Operations would benefit from more control over the production system.

2.7 Chapter Summary

Boeing and the aerospace industry have continued to evolve with the forces of globalization, competition, and industry dynamics. The industry has learned important lessons from challenging growing pains. In addition to the external factors and context, Boeing's internal dynamics must be considered when creating any solutions. Chapter 3 discusses multiple elements of supply chain and begins the transition to considerations that should be thought about when making sourcing decisions.

3 Supply Chain Considerations

3.1 Outsourcing and Offshoring

Outsourcing[8] and offshoring[9] bring benefits for corporate management. These include access to talent, lower costs, and additional resources. At the same time, the transition from vertically-integrated firm to virtually integrated supply chain entails challenges such as loss of control, potential quality issues, reduced flexibility, and customer or labor backlash. It is not unheard of for firms to be disappointed by their efforts at outsourcing and offshoring. Additional traps to avoid are suppliers diffusing proprietary technology to competitors, becoming too reliant upon suppliers, and losing integration abilities (Parker & Anderson Jr., 2000).

Although, outsourcing can provide access to labor and lower labor costs, it can come at the expense of intellectual property exclusivity. Technology, operating methods, and trade secrets often must be transferred to the supplier. Therefore, some companies retain manufacturing in their home country or within their own foreign facility to protect themselves from the risk of giving away the knowledge and capability that provides their competitive advantage. However, there are challenges associated with captive offshoring, setting up company-owned operations in another country (often for greater company control). Skilled managers must be sent to the new site to train workers and in some cases, workers may travel to the home country for training. Bringing over existing employees and transferring work to the offshore facility can be intimidating. Additionally, there are challenges with setting up logistics, quality control, and transportation to the customer market. It can be difficult to improve productivity levels and often-times, the best and most talented professionals remain at the firm's home office.

Foreign production often creates improved market access to the country of production. The company will not only have the opportunity to sell high-quality airplanes in the US home market, but also at other countries throughout the world (Plunkett, 2009).

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[8] The hiring of an outside company to perform a task that would otherwise be performed internally by a firm.

[9] A situation where typically developed economies send both knowledge-based and manufacturing work to other nations. This is often driven by lower labor cost and access to human and material resources. Examples at Boeing are fabrication and the design and engineering of components.

While outsourcing can reduce financial risk and improve market access, the firm must be careful not to transfer too much knowledge to partners. Short-term financial gains could come at the loss of long-term strategic value. The partners of today could become competitors of tomorrow.

3.2 Partner Relationships

There is a wide spectrum of supplier relationship types. Relationships can range from an arms-length model to a strategic partner or even a fully-owned subsidiary. Figure 2 summarizes characteristics of these relationship types organized from outsourced to vertically-integrated.

Type of Relationship	Description	
Arm's length relationships	Traditional, cost-based, free market, short duration, purchase-order driven relationships	Outsourcing ↓
Modified vendor relationships	Value-added services (e.g., supplier managed inventories)	
Long-term contracts	Long-term supply contracts	
Non-equity based collaboration	R&D consortia Cross-marketing agreements Cross-production agreements Joint purchasing activities	
Minority equity investments	Invest in supplier	
Licensing arrangements	Provide license to supplier in technology that host firm develops but in which it wants to limit investments	
Investment integration	Coordinate investment jointly	
Joint ventures or strategic alliances	Allow firms to exchange certain goods, services, information or expertise while maintaining a formal trade relationship on others	
Asset ownership	Host firm retains ownership for critical assets in adjacent stages of the industry chain, but contracts out all other aspects of ownership and control	
Full ownership	Host firm fully owns activity	Vertical Integration

Figure 2: Spectrum of Relationships with Suppliers (Adapted from Beckman & Rosenfield, 2008)

Boeing has several relationships with suppliers that have spanned multiple airplane programs. These suppliers provide critical expertise and capacity to complement Boeing's work on the airplane. These partners have grown in importance as Boeing has shifted from a build to print model to giving those partners increasing levels of control. This has progressed from detail design to system design to suppliers creating their own production system and managing their own supply chain reducing the investment required in personnel and assets by Boeing. Some of these strategic relationships are specific to Boeing while other suppliers have begun to partner with Airbus and other airplane manufacturers.

Oftentimes, manufacturers maintain relationships with key suppliers. In the case of Boeing, they have traditionally partnered with the "Japanese Heavies" which include Mitsubishi Heavy Industries, Kawasaki Heavy Industries, and Fuji Heavy Industries. This group of suppliers forms the Japan Aerospace Industry (JAI) consortium which produces aerospace components and has participated in every program since the 747 in the late 60's (Wallace, Boeing Had to Have 7E7 Help, Experts Say, 2003). These companies are also part of the Japan Aircraft Development Corporation (JADC) consortium. This long-term partnership is organized by the Japanese government to coordinate research and development as well as manage "bids" from the heavies to deliver components to Boeing. They proactively coordinate their joint share of airplane programs. JAI has increased their share from 15% on the 767 to 21% on the 777 and 35% of the airframe on the 787 (Inoue & Shiraki, 2003).

During development programs like the 747-X and Sonic Cruiser, suppliers provided development resources in hopes of establishing a relationship with the manufacturer and earning the production business. The incumbent supplier can usually expect to be awarded the production contract. All 787 partners were members of the Sonic Cruiser development team. Table 1 lists the 787's major airplane sections and associated suppliers.

Forward Fuselage	Spirit AeroSystems, Kawasaki Heavy Industries
Center Fuselage	Alenia Aeronautica
Rear Fuselage	Vought Aircraft Industries
Outboard Wings	Mitsubishi Heavy Industries
Center Wing Box	Fuji Heavy Industries
Vertical Tail Fin	Boeing Fabrication (Frederickson, WA)
Horizontal Stabilizers	Alenia Aeronautica

Table 1: Major Airframe Structure Suppliers to the Boeing 787

In the case of the 787 Program, the partner invests its own money for development and capital investment and shares in the profits from sales of the 787. The original contracts were also written that suppliers would not be paid by Boeing until the first plane is delivered (Greising & Johnsson, 2007). This program can be viewed as a joint venture between Boeing and several large companies – including the Japanese heavies.

Relationships with suppliers are also affected by the sourcing process. Two general approaches are the price-based approach and the knowledge-based approach. The price-based approach can pit suppliers against the manufacturer and encourages an arms-length relationship. Products and materials are purchased through competitive bidding and each side reveals as little information as possible. Purchasing managers focus on increasing cost savings and suppliers submit bids to win the contract. After winning the bid, suppliers may charge exorbitantly for design changes. The knowledge-based approach sets prices in a way that reflects the supplier's true economics and provides them a reasonable profit margin. The OEM and supplier work together to get from the supplier's current cost to a target "should cost"[10] while aligning the incentives for lowering cost, raising quality, and continuous improvement and innovation in future years. With fewer suppliers and a strategic relationship focus, joint coordination is improved for better quality and smaller purchasing departments reduce overhead costs.

Steps can be taken to implement knowledge-based sourcing. They include establishing suppliers as strategic long-term partners, systematizing waste elimination through collaboration across the supply chain, getting design right the first time, and respecting and developing human capabilities. As these new suppliers mature, they achieve stability, improved production, and lean operations (Jackson & Pfitzmann, 2007). Even while Boeing focuses on maintaining strong ties to its key partners, they must continue to invest in their own experienced work force to build capabilities and nurture relationships.

3.3 Outsourcing Risk

Risks have increased in recent years due to increases in outsourcing, offshoring, and lean manufacturing. If properly managed, outsourcing can result in lower costs, better performance, and improved global sales. If improperly managed, the company may face embarrassing and costly delays, quality issues, and cost overruns. There are several types of risk when evaluating investment proposals. Technology risk can arise from uncertain developments of new technology, the obsolescence of old technology, and from compatibility with other technologies. Commercial risk transpires from variability of the customer market and regulatory environment. Economic risk is

[10] The "should cost" reflects an estimate of the cost to produce a quality component based on an understanding of raw material costs, efficient manufacturing costs, production overhead cost, and a reasonable profit margin.

derived from uncertainty in the cost and benefit forecast. Implementation risk is linked with buy-in, schedules, training and integration with other changes.

There are many types of supply chain risk, especially when combined with foreign outsourcing. Figure 3 orders a partial list of risks by how well known and controllable they are. On one end of the spectrum are relatively unknown and uncontrollable natural disasters while execution problems are relatively known and controllable.

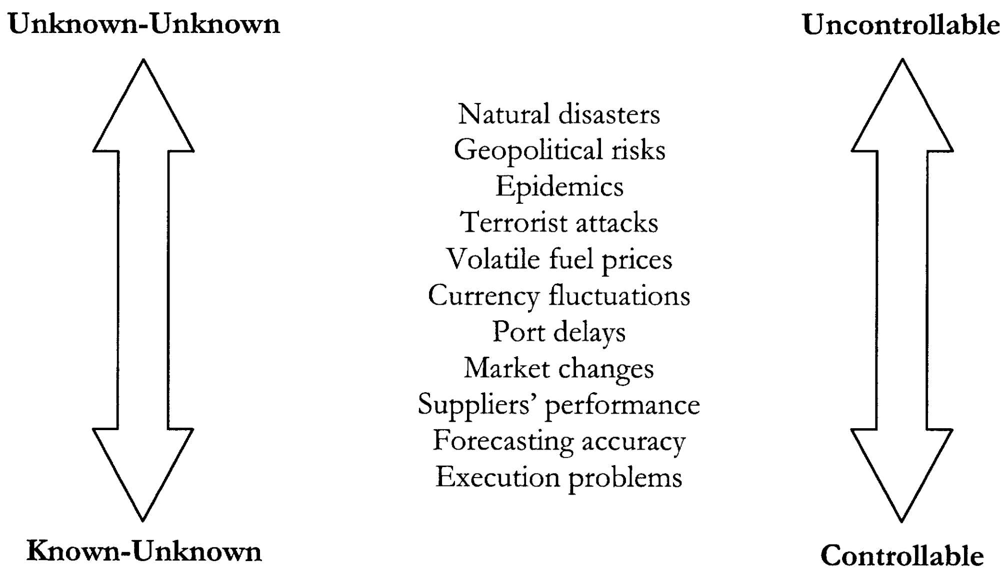


Figure 3: Sources of Risk (Simchi-Levi, 2008)

Methods of dealing with these risks include flexibility and speed, redundancy, network planning, risk sharing, and risk pooling.

Another outsourcing risk is loss of knowledge continuity for future generations of employees. There is the potential for generational gaps in employees, especially with infrequent new product launches and demographic shifts. It is critical that younger generations of employees learn from the experience of their predecessors as well as from their own experience. This is particularly important when you consider that 78 million baby boomers will be retiring in the next 20 years. This demographic shift is especially critical in large engineering organizations with incumbent, technical expertise (Kim, 2009). One of the ways that the organizational forgetting can manifest itself is in periodic failure. In the bridge industry, there has typically been one major failure every thirty years.

The focus on building on pushing successful designs without sufficient focus on avoiding failure often manifests itself without the occasional painful reminder (Petroski, 2006). The transfer of tacit knowledge and introspection of failure are critical aspects of avoiding future disaster.

There is also the risk that the outsourcing firm will become technologically uncompetitive or lose market power. If it fails to reinvest in developing its own capabilities, it may not keep up with the best new methods to design and manufacture its key products, and could even be overtaken by its more knowledgeable suppliers. In shifting capital-intensive operations to outside suppliers, companies may be handing over the skills and processes that have distinguished them in the marketplace.

3.4 Supply Chain Proximity

There are multiple dimensions to measure proximity besides the physical distance from one facility or organization to another. As discussed in Clockspeed by Charles Fine, the critical dimensions are geographic, organizational, cultural, and electronic. Geographic proximity can be measured by physical distance, organizational proximity concerns corporate structure and processes, cultural proximity includes language, customs, and laws, and electronic proximity captures the commonality of virtual forms of collaboration. Integral supply chain architecture has a close linking along these dimensions of proximity while modular supply chain architecture has low proximity and looser linkages between supply chain elements.

Integral supply chain architecture is required when there will be a high degree of interaction between organizations. Communications are improved and development time is reduced by facilitating needed transactions. Shorter physical distances aid frequent communication and relationship development. Similar cultures, processes, and organizational structures enable closer collaboration. Transferring updates through common software and tools reduces conversions and enhances the flow of information. Conversely, modular supply chain architecture, often used with standard components, is more of an arm's length relationship where the supplier may be far away, has few interactions necessitating similar culture to deliver the part, and does not need closely-linked electronic systems. Firms tend to be most successful when there is consistency between the supply chain and product architectures. Therefore, an integral product should be produced with an integral supply chain (Fine, Clockspeed, 1998).

Firms are attracted to locations with large market size, large pools of engineers, and high national capability. When designing global product development, one should also give special consideration to product complexity, specificity, strategic importance, and the designing firm's capability. These attributes should influence the type of relationship pursued. The types of relationships are captive offshoring (typically least technologically advanced, high strategic importance), global outsourcing (high technological capability with low complexity, low specificity), global partnerships (high complexity and moderate to high technological capability, low strategic importance), and vertical integration (highest strategic importance) (Makumbe, 2008).

3.5 Production Networks

When designing their production network, companies should reflect on how their industry is organized. It may be a city cluster, nation, region, or the globe. There have been many regional aircraft production networks over time. These networks hold concentration of industry-specific talent and capacity. Currently, the five largest aviation clusters responsible for about 65% of the world's aircraft production are located in Dallas-Forth Worth, Montreal, Puget Sound/Seattle, Toulouse, and Wichita. These clusters are deep in expertise which is beneficial for complex systems (Aboulafia, 2008).

The most prominent group of aviation clusters at a given moment has not been constant over time. While difficult to create, they are easier to destroy. That is why some regions are providing tax breaks and other incentives to encourage the industry to stay. Sixty-three industry and research partners from eleven European Union countries have created a framework to improve systems integration called the Value Improvement through a Virtual Aeronautical Collaborative Enterprise (VIVACE). The United Kingdom has laid out a roadmap for research, design, and production through the National Aerospace Technology Strategy (NATS). Also within the UK, The Integrated Wing Technology Validation Programme (IWATVP) is a national effort designed to enable a step change improvement in wing technologies and configurations.

Still, lower labor costs and more flexible workforces have contributed to geographical shifts. It is easier to train flexible employees than experienced, but inflexible workers. The UK, Southern California, and Long Island all were home to major aircraft industries in the past. A portion of production shifted away as manufacturing disaggregated, airframes became less important, transportation cost and time decreased, and trade has globalized.

3.6 Views on Enterprise Boundaries

The theory of business ecosystems characterizes two types of firms: blue firms and red firms (Piepenbrock, Fine, & Nightingale, 2008). Blue firms have modular enterprise architecture. They work with a set of stakeholders, but deal with those stakeholders in an outside manner. Red firms have integral enterprise architecture. Its enterprise boundary is inclusive of the major stakeholders.

Based on Piepenbrock's empirical observations, firms of modular enterprise architecture focus on the maximization of shareholder value, have narrow enterprise boundaries, and hold larger quantities of lower quality interactions. Firms of integral enterprise architecture tend toward the maximization of stakeholder surplus, hold broader enterprise boundaries, and have a smaller quantity of higher quality interactions. Figure 4 summarizes the differing characteristics between blue and red firms.

Modular Enterprise Architecture	Characteristic	Integral Enterprise Architecture
Maximization of Shareholder Value	Firm Objective	Maximization of Stakeholder Surplus
Narrow	Enterprise Boundary	Broad
Simple (High quantity of low quality relationships)	Stakeholder Interface	Complex (Low quantity of high quality relationships)

Figure 4: Typology of Enterprise Architectures (Piepenbrock, Fine, & Nightingale, 2008)

Enterprise architectures influence firm performance by enabling and constraining choice in key competitive variables. Based on their research, firms of integral enterprise architecture tend to have higher revenue, profit, and market capitalization growth than firms of modular architecture over the long term. Value generation is enabled by a virtuous cycle of trusting employees, and employees delivering continuous improvement. Toyota is considered the ultimate red company. In the commercial airplane business, Airbus is considered to be a red firm while Boeing is a blue firm.

The enterprise boundary theory concludes that different stages of industrial growth are better suited to different types of companies. Figure 5 illustrates how in the early, uncertain stages of growth, blue firms dominate because they are able to quickly evolve. Due to immature product and process architecture, no firm knows who is best to partner with. As the industry matures, red firms tend to dominate. Blues firm may succeed again with the jump to a new technological S-curve or by becoming more purple or red. Uncertainty remains as to what happens when there are multiple red firms, when the market declines, or whether evolution a blue firm can evolve into a red firm.

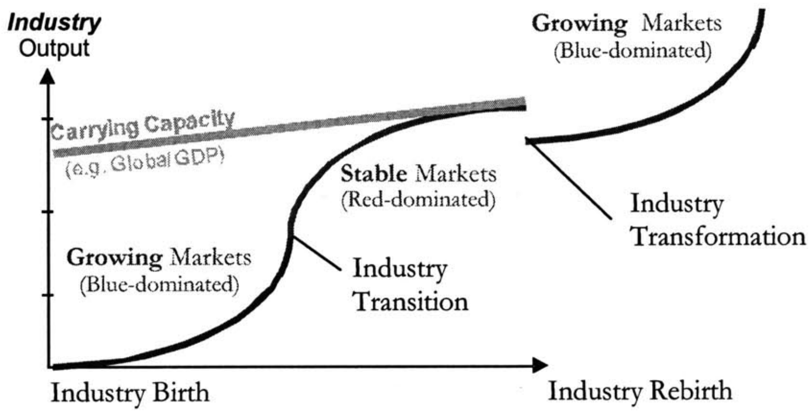


Figure 5: Industry and Enterprise Evolution (Fine, Auto Industry Dynamics, 2009)

While Boeing is evolving towards an integral enterprise structure, Airbus has passed Boeing in commercial airplane revenue. However, there are changes occurring in the airplane manufacturing industry. Aircraft structure materials are shifting from aluminum to high-performance composites and there is some pressure to vertically disintegrate. Because of these changes, there may be potential for Boeing to wrest back industry leadership by selectively developing its own capabilities and building relationships with partners that have the complementary skills for the future.

3.7 Chapter Summary

Supply chain decisions are important to satisfy strategic decisions and create competitive advantage. In recent times, outsourcing, offshoring, and their associated risks have increased in frequency. Geographic networks for research, design, and manufacturing are forming across the globe. At the same time, companies are redrawing their enterprise boundaries by choosing to work with fewer suppliers, but work more closely with their selected suppliers to create close-knit long-term partnerships. These aspects combined with supply chain architecture and company proximity are important aspects of creating a high-performing operation.

4 Technology and Financial Considerations for Outsourcing Decisions

This chapter builds on the previous chapter's supply chain considerations to discuss product, technology, and financial factors that should affect the vertical integration decision. The way product is configured, what technology goes into the product, cost, and the way cost is calculated are all important considerations that will affect the likelihood of success in vertical integration and outsourcing situations.

4.1 Product Modularity

Product modularity attempts to describe the way that a product is structured. Modular product architecture contains a flexible group of subsystems (modules), with one to one mapping of highly standardized interfaces and weak interdependencies. Integral product architecture contains a tightly coordinated group of subsystems with one to many mapping of complex, interdependent, and nonstandard interfaces.

Products that do not fully meet most customers' desired performance levels tend to be integral in order to maximize their performance. When technology improves and product performance overshoots customer needs, product competition shifts. It moves from performance to flexibility, time to market, and customization. These needs are better served by modular product architecture (Christensen, 1994).

Airplanes are high-performing, integral, and durable products. They strive to overcome the demanding requirements for efficiency, customer comfort, and speed. Due to its equally-demanding aerodynamic, load-bearing, weight, and fuel-carrying requirements, the wing remains a highly integrated product to maximize its performance. The airplane wing has few standard interfaces and is one of the most complex and integrated structures on an airplane. As will be discussed in this chapter's Design Structure Matrix, there are many types of interactions between multiple wing subsystems.

Boeing historically engineers a baseline design and makes "trades" - compromises between differing objectives - to increase the overall value proposition of the aircraft. A higher degree of integrality requires additional iterations to complete the design. The larger number of iterations results in a larger number of transactions and related costs. Where possible, it is beneficial to maintain the most integral parts of the value chain internally to speed development and minimize transaction friction.

When considering which components of the wing may be outsourced, one concern is the density of interaction. A key question is: "where are the dense interfaces?" Poor communication can result when design interfaces cross organizational boundaries. Therefore, processes and organizations should be designed to match specific product architectures (Eppinger, 2001). The outboard wing is naturally separated into several major subsystems with the foremost splice between the outboard wing and wing center section. Figure 6 highlights three of the major sections of a typical airplane wing. Major subsystems are itemized in the Work Breakdown Structure (WBS). The WBS lists both structural elements and systems of the wing. These will be the elements used in the Design Structure Matrix.

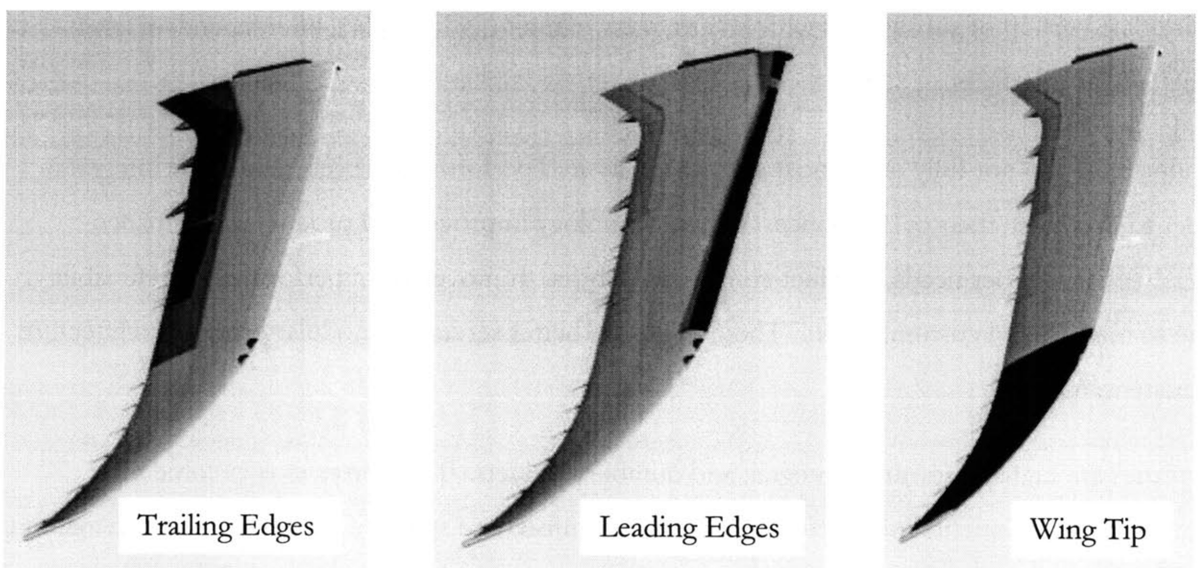


Figure 6: Major Sections of an Outboard Airplane Wing (The Boeing Company, 2008)

WBS - Structural Elements of the Wing

Outboard Structural Box – rear spar, front spar, upper panel, lower panel, ribs, stringers, and doors.

Movable Trailing Edge – the rearmost edge of a wing which includes the flaps, aileron, and spoilers

Movable Leading Edge – the foremost edge of a wing composed of multiple slats

Fixed Trailing Edge – the rearmost edge of a wing that includes the structure supporting the movable trailing edge, landing gear beam, wingtip closure rib, vapor barrier components, and its own panels

Fixed Leading Edge – the foremost edge of a wing that includes the structure supporting the slats, airload ribs, wingtip closure rib, vapor barrier components, and its own panels

Wing Tip – the small, rigid, outboard edge of a wing that stabilizes the plane in flight

WBS - Systems in the Wing

Tubing – hydraulic, fuel lines, oxygen, and fire extinguishing

Avionics – data control systems enable interaction with aircraft systems including navigation, communication and flight control, and airplane health management

Flight Control Systems – consist of flight control surfaces, connecting linkages, and the necessary electrical and hydraulic actuators to control an aircraft's direction in flight.

Hydraulic Systems – engine and electrically-driven pumps and accumulators used to aid the movement of flight controls

Electrical – electronic distribution system to direct current from generators and batteries

Fuel Systems – tanks and pumps to contain and distribute fuel

Electromagnetic Effects (EME) – system to dissipate energy from lightning strikes and keep it isolated from the fuel

Environmental Control System (ECS) – electrical and pneumatic system to prevent ice build-up on the wing and provide cabin air

The Design Structure Matrix provides a compact representation of a complex system and captures the interactions between system elements. For each subsystem to subsystem relationship, there can be multiple types of interactions. Four groupings (Spatial, Energy, Information, and Material) of interaction types are used to characterize the Figure 7 wing subsystem interaction matrix relationships.

Types of Interactions

Spatial (S): Needs for adjacency or orientation between two elements.

Energy (E): Needs for energy transfer between two elements.

Information (I): Needs for information or signal exchange between two elements.

Material (M): Needs for materials exchange between two elements.

(Pimmler & Eppinger, 1994)

Wing Subsystem		A	B	C	D	E	F	G	H	I	J	K	L	M	N
Outboard structural box	A				S E M	S E M	S E	S E I M		S E	S E M	S I	S E I M	S E	S M
Movable Trailing Edge	B				S E M			S E I M	S I	S E I	S E M	S I		S E	
Movable Leading Edge	C					S E M		S E I M	S I	S E I	S E M	S I		S E	
Fixed Trailing Edge	D	S E M	S E M				S E I	S E	S E	S E	S E	S E		S E	
Fixed Leading Edge	E	S E M		S E M			S E I	S E	S E	S E	S E	S E		S E	
Wing Tip	F	S E			S E I	S E I			S I			S I		S E	
Tubing	G	S E I M	S E I M	S E I M	S E	S E					S E I M		S E I M	S E	S M
Avionics	H		S I	S I	S E	S E	S I			I					I
Flight Control Systems	I	S E	S E I	S E I	S E	S E			I						
Hydraulic Systems	J	S E M	S E M	S E M	S E	S E		S E I M							
Electrical	K	S I	S I	S I	S E	S E	S I								E
Fuel Systems	L	S E I M						S E I M							
Electromagnetic Effects	M	S E	S E	S E	S E	S E	S E	S E							
Environmental Control System	N	S M						S M	I			E			

Figure 7: Interaction Matrix – Outboard Wing

Each of the boxes with zero to four types of interaction is translated to a score. The score is equal to the number of types of interactions up to a maximum score of three. The entries in each row are summed to a total score for each wing subsystem. See Figure 8 for the results. A higher score generally represents a higher level of interaction and integrality. These scores suggest which wing subsystems are more or less integral than others. With a score of 25, the outboard structural box is the most integral subsystem. With scores of 6, the environmental control and fuel systems are relatively less integral with other subsystems. When there is more product integrality, more care should be taken to facilitate transactions as highly integrated systems require a larger number of iterations and coordination. This can be done by vertically-integrating, increasing the supply chain proximity, and through the central coordination of interfaces.

Wing Subsystem		A	B	C	D	E	F	G	H	I	J	K	L	M	N	Score
Outboard structural box	A		0	0	3	3	2	3	0	2	3	2	3	2	2	25
Movable Trailing Edge	B	0		0	3	0	0	3	2	3	3	2	0	2	0	18
Movable Leading Edge	C	0	0		0	3	0	3	2	3	3	2	0	2	0	18
Fixed Trailing Edge	D	3	3	0		0	3	2	2	2	2	2	0	2	0	21
Fixed Leading Edge	E	3	0	3	0		3	2	2	2	2	2	0	2	0	21
Wing Tip	F	2	0	0	3	3		0	2	0	0	2	0	2	0	14
Tubing	G	3	3	3	2	2	0		0	0	3	0	3	2	2	23
Avionics	H	0	2	2	2	2	2	0		1	0	0	0	0	1	12
Flight Control Systems	I	2	3	3	2	2	0	0	1		0	0	0	0	0	13
Hydraulic Systems	J	3	3	3	2	2	0	3	0	0		0	0	0	0	16
Electrical	K	2	2	2	2	2	2	0	0	0	0		0	0	1	13
Fuel Systems	L	3	0	0	0	0	0	3	0	0	0	0		0	0	6
Electromagnetic Effects	M	2	2	2	2	2	2	2	0	0	0	0	0		0	14
Environmental Control System	N	2	0	0	0	0	0	2	1	0	0	1	0	0		6

Figure 8: Wing Subsystem Interaction Scores

4.2 Recurring and Non-Recurring Cost

When making sourcing decisions, cost is one of the most important factors. Traditionally, airplane manufacturers have made significant investments in non-recurring cost to tool up for the development and production of a new airplane program. Development costs for the Boeing 777 were estimated between $6 billion and $8 billion dollars (Wallace, Boeing Had to Have 7E7 Help, Experts Say, 2003). The recent Airbus A380 was projected to have cost $10.7 billion of which $7.4 billion was for aircraft development and $3.3 billion for non-recurring tooling investment (Gellman, Weber, Hamlin, & Aboulafia, 2004). Often, many years pass before an airplane program's profits pays off the initial investment. There are risks in the profitability of an airplane program (the NPV) depending on the investment required, the number of sales, and the margins. Despite variability due to unforeseen challenges with new product development programs, Boeing considers initial investment to be a relative known when compared with the total number of airplane sales. This risk can be decreased by reducing the total upfront investment amount or by transferring risk to the supply base through outsourcing and contracts. The Boeing 787 financial risk-sharing approach is discussed in Chapter 6.2.

Recurring costs are paid over the course of an airplane program. When strictly considering cost, the manufacturer should try to reduce their cost whether that is achieved by producing internally or outsourcing. Consider the case of a composite airplane wing. There are relatively few suppliers capable of building an airplane wing and even fewer with the capability to build composite wings.

When there is a requirement for financial capacity to invest in the capital equipment to build the airplane wings, the list grows even smaller. Those few suitable suppliers have strong market power. In the case the buyer and supplier have a price-based relationship (as opposed to a trusting knowledge-based relationship), the supplier would exert their power and the buyer may be inclined to vertically integrate the wing. This consideration must be balanced with sharing investment cost and other vertical integration decision factors.

4.3 Accounting Methods

Typically, part costs are determined through traditional cost accounting. This methodology uses an overhead rate to burden the employee direct labor cost. While commonly used, this simplifying assumption may lead to inaccurate cost information and improper decisions. A fictitious example is used to demonstrate the importance of accounting methodology and how flawed use may lead to poor decisions.

Consider *"Mettle" Bender*'s costs for producing its current lineup of *Widget^{Originals}*. There are several costs grouped into different categories. Those are material cost, direct labor cost, and overhead cost. Labor cost is calculated based on the working hours per year. The overhead rate is determined by dividing the total overhead cost by the direct labor cost. This gives a rate of 279% which is a large burden to add onto each worker. This calculation is based on the assumption that overhead costs linearly scale with the number of labor hours.

"Mettle" Bender Corporation Annual Budget (for *Widget^{Original}* Production)

	Number	Cost per	Annual cost	Monthly Cost
Materials Cost	330000	$15.00	$4,950,000	$412,500
Direct Labor	25	$46,368	$1,159,200	$96,600
Overhead Costs:				
Machines	20	$6,000	$120,000	$10,000
Outside process	1	$95,000	$95,000	$7,917
Other costs	1	$10,000	$10,000	$833
Maintenance	8	$50,000	$400,000	$33,333
Engineers	13	$80,000	$1,040,000	$86,667
Managers	9	$65,000	$585,000	$48,750
Materials Handling	12	$45,000	$540,000	$45,000
Support People	8	$55,000	$440,000	$36,667
Total Overhead	72		$3,230,000	$269,167
Total Costs			$9,339,200	$778,267

Days/Week	5
Shutdown (weeks/year)	2
Shift Hours	7.5

Labor Rate	$24.73
Overhead Rate	279%

Table 2: "Mettle" Bender Cost Summary

The conversion costs, primarily consisting of labor cost, are not correctly allocated because of the gross overhead allocation. It does not directly allocate the true costs and overestimates the amount. The company is considering producing a new product, called the *Widget*⁺. 3000 parts must be produced per month and material cost alone amounts to $23. Using the standard cost approach, significant overhead cost is applied and the profit has approximately 5% margin.

Standard Cost	**Product: *Widget*⁺**
Material Cost	$23.00
Labor Time (seconds)	750
Labor Rate	$24.73
Labor Cost	$5.15
Overhead Rate	279%
Overhead Cost	$14.36
STANDARD COST	$42.51

Profitability using Standard Cost	
Price	$45.00
Standard cost	$42.51
Profit /unit	$2.49
Margin	5.5%

Monthly Qty	**Monthly revenue**
3000	$135,000
	$127,523
Profit	$7,477
Margin	5.5%

Table 3: *Widget*⁺ Standard Cost

News of great savings from low cost country sourcing spurred *"Mettle" Benders* to investigate a quote from a Chinese supplier. Taking into account the landed cost and overhead cost associated with managing the outsourcing, there is a cost savings over the standard rate and the margins impressively jump to over 29%.

Profitability with Low Cost Outsourcing		Monthly Qty	Monthly revenue
Price	$45.00	3000	$135,000
Outsourcing Landed Cost	$29.00		$87,000
Outsource Overhead %	10.0%		
Outsource Overhead Cost	$2.90		$8,700
Total Cost	$31.90		$95,700
Profit/unit	$13.10	Profit	$39,300
Margin	29.1%	Margin	29.1%

Table 4: *Widget*$^{+}$ Low Cost Outsourcing

Many companies stop at this point, but this firm has heard about yet another way to calculate cost. The true cost to *"Mettle" Benders* is most accurately reflected with a value stream costing approach. This method looks at the true costs and only adds the relevant additional costs as opposed to applying the overhead rate. With the new sales included, the value stream sees rising costs. However, additional overhead costs are only added when they are directly attributable. The value stream profit should be considered.

Profitability with Value Stream Costing (2 new machines and 2 operators)			
	Current State (Monthly)	**New *Widget*$^{+}$ Order**	**Value Stream with New Order**
Revenue	$1,000,000	$135,000	$1,135,000
Materials Costs	$412,500	$69,000	$481,500
Direct Labor Costs	$96,600	$7,431	$104,031
Machine Costs	$10,000	$952	$10,952
Other Conversion	$259,167		$259,167
Value Stream Profit	$221,733	$57,617	$279,350
Return on Sales	22.2%		24.6%

Table 5: *Widget*$^{+}$ Value Stream Cost Change

The costs for original factory output of *Widget*^{Originals} and *Widget*$^{+}$s using the three methods is listed in Table 6. As can be seen from the comparison, using standard costs shows the highest cost and lowest margin. Looking at cost impacts only, outsourcing to China significantly increases the margins over producing internally. If taken at face value, any firm would be tempted to outsource for the *Widget*$^+$ production. Going one step further into value stream costing, we can understand that the unique conversion costs are for the two extra machines and two additional operators. No other overhead costs are applied. Surprisingly, this accurate reflection of the true cost shows that it is most profitable to produce internally.

	Summary of the Alternatives (Monthly Figures)			
	Widget *Original* **Output**	**New *Widget*$^+$ Order**		
		Using Standard Costs	**Outsource to China**	**Value Stream Costing**
Revenue	$1,000,000	$135,000	$135,000	$135,000
Materials	$412,500	$69,000	$87,000	$69,000
Conversion	$365,767	$58,523	$8,700	$8,383
Profit	$221,733	$7,477	$39,300	$57,617
Return	22.17%	5.5%	29.1%	42.7%

Table 6: *Widget*$^+$ Cost Comparison Summary

Even though the importance of accounting methodology is not intuitive, traditional cost accounting may give a false picture of financial benefits of outsourcing. Lean accounting more accurately reflects the true costs inherent in production alternatives.

4.4 Implications of the Shift from Aluminum to Composites

To put the shift from aluminum to composite structures in perspective, it is helpful to consider the case of the transition from wood and fabric to metal airplanes. A structural revolution took place in the late 1920s and the early 1930s. Many new features like retracting landing gear and stressed-skin construction are attributed to the change in building material. While new materials can extend the performance envelope, one must not be too quick to assume that the key innovations were developed to take advantage of metal construction. These features emerged independent of material and in many cases were first used in wooden airplanes (Jakab, 1999). This same time period saw many innovative new airplane manufacturers emerge. However, two aircraft are often cited as the embodiment of the structural revolution: the Boeing 247D and the Douglas DC-3. These two revolutionary planes helped position Boeing and Douglas for decades of airplane success.

Considering the structure and design of aircraft, today's designs have been refined for many decades and are already architecturally efficient. While improved material properties of composites opens some options like longer airplane wings for a better lift to drag ratio, this does not mean that airplanes will switch to a drastically different architecture. Other benefits of composites are reduced weight, improved fatigue and corrosion resistance, fewer parts, and reduced maintenance costs. From a composite structures design standpoint, the holy grail is to create a one-piece airframe structure that eliminates the use of all fasteners. Implementing this vision is not feasible in the near or medium term due to required material and technology advancements, the facility size required, and even the ease of installing components inside the aircraft.

As discussed by Utterback and Abernathy, product innovation progresses through multiple stages where competition is first based on functional product performance, then product variation, and finally cost reduction. Product innovation is strongest at first until the transition to where most of the change is through process innovation. Major new products often have a more fluid pattern of change. The competitive advantage is typically superior product performance – in this case, reduced weight, improved corrosion-resistance, and increased fatigue life. In the early stages, there are uncertain targets that mature into well-articulated design objectives. There is an early flurry of product performance requirements and design criteria that cannot be effectively defined, and relative importance can be relatively unstable. With this in mind, the extra anticipated risk with the 787 program would tend to lead Boeing towards a longer (as opposed to its shortest) target development cycle. With task uncertainty early in a product's development, the productive unit must maximize its ability to process information (Abernathy & Utterback, 1978)

Production technology is efficient, more equipment-intensive, and specialized. Due to its integrated nature, innovation is typically more incremental and cumulative.

A successful company should concentrate its learning during the early technology development stages to gather significant knowledge and capability to prepare itself for a strong future. When involving a technology that is integral to the product and holds much promise for performance improvement, like composite airframe structures, it is better to keep the work internal to the organization.

4.5 Composites Capability

A firm's capability is important to innovate and execute the production of a product. Advances in propulsion, systems, and airframes will be responsible for delivering many large aircraft improvements in the future. Since this study explores the production of a composite airplane wing, aerospace composites usage will be discussed.

Experience with composites application in aircraft production started several decades ago. There has been an increasing amount of composites technology implemented on commercial programs over the years. Prior to the 787, composites usage for manufacturing the airframe was fairly limited. It began with control surfaces on programs like the 747 and expanded to larger applications like the 777 vertical tail fin. The 787 program made a large jump in composites usage by fabricating the airframe structure and approximately 50% of the total airplane weight with composites (See Figure 9). Boeing has made significant technical advances and taught its suppliers to wrap composite fuselage barrels and lay down carbon fiber tape. The Airbus A350 XWB also uses significantly more composites than its previous airplane. While it employs a composite airframe, one of the major differences is that it will use composite panels as opposed to wrapping one-piece barrel sections like the 787. The recently launched Bombardier C-series utilizes a composite airframe. The MHI regional jet will utilize composite wings.

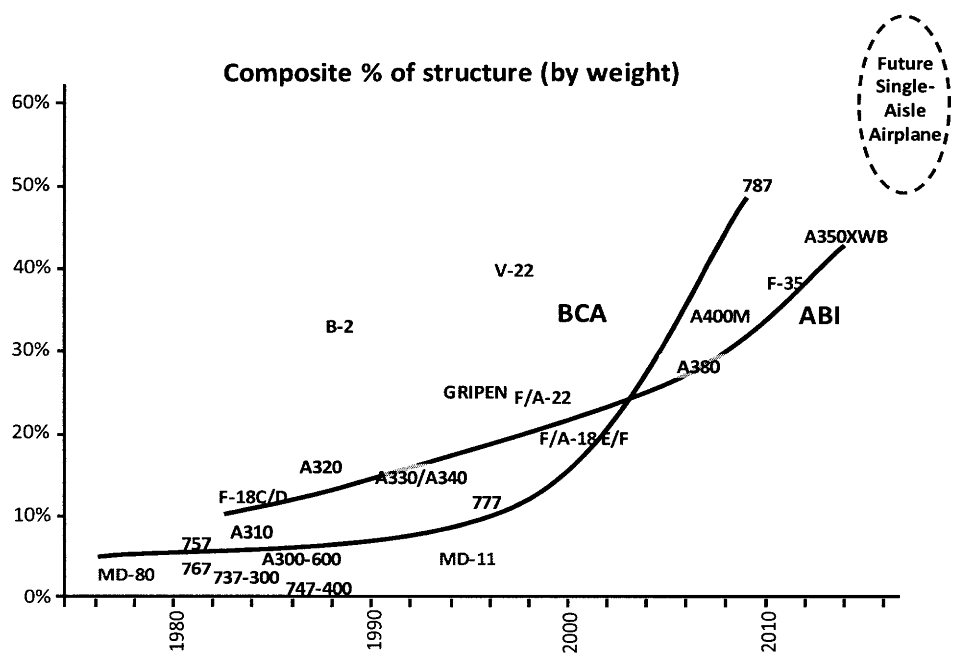


Figure 9: Growing Aerospace Composites Usage (Aerostrategy Management Consulting, 2006)

Design advantages are reduced weight, improved fatigue and corrosion resistance, and new design possibilities. Other potential benefits are fewer parts, less frequent inspection and maintenance, and a new realm of production possibilities. Carbon fiber preimpregnated with resin (unidirectional tape, unidirectional tow, and fabric) and dry fiber preforms with resin infusion are the two major types of carbon fiber production. The 787 carbon fiber component fabrication process uses mainly automated application of preimpregnated material (Boeing, 2008).

Both composites product design and composites process design are still in the early stages of development and evolving at a rapid rate. As consistent with Utterback's theory on industrial innovation, the product design is more mature than the process design. There still exists great opportunity to advance composites material properties, design, and fabrication process. Material properties can improve their impact resistance and electromagnetic performance. Design progress can be made in geometry optimization, modeling accuracy, and joining techniques. Desired manufacturing improvements are faster material buildup, faster non-destructive inspection (NDI), and lower cost tooling. Other advances include improved curing processes and significant reductions of required inspection.

Since there are a limited number of suppliers with the technical and financial resources to partner with Boeing on a program like the 787, Boeing must nurture relationships with the most capable partners. They must also maintain a portion of the complex composite structure design and production internally so that they can continue to develop and incorporate the latest advancements, and be a smart customer.

4.6 Financial and Enterprise Risk

Oftentimes, major sourcing decisions are referred to as strategic sourcing. Pritchard and MacPherson describe those same actions as strategic destruction when they are done in a manner that trades for short-term financial gain at the expense of long-term value. As build-to-print subcontracting relationships convert to risk-sharing systems integration partnerships, substantial technology transfer and movement of tacit knowledge occurs with the design and production. While enticing from a financial standpoint, there is the possibility that these risk-sharing partners designing increasingly complex components will become future competitors.

The airplane systems integrator model combined with global subsidies has altered the way that aircrafts are financed. This model reduces financial risk, increases market access, limits launch costs, and uses foreign risk-sharing partners as a means to motivate foreign government funding. The globalization of aircraft production means that highly-skilled jobs will also move to those foreign locations. For the first time on the 787, the system integration process gives foreign partners the control over design, manufacturing, and sub-tier selection. Even though Boeing and Airbus have the financial depth to fund a multi-billion dollar airplane program, they choose not to self fund their new projects. The outsourcing under the systems integration model is not driven by the desire to minimize total system-wide costs. Instead, the observed goal is to transfer financial risk from the OEM to the supply chain (Pritchard & MacPherson, 2007).

Internal design and production develops the workforce to ensure technical expertise and support the application of newly developed technologies. Less experience and learning from building will reduce the OEM's knowledge and ability to improve its design and build processes. It may also inhibit the firm's ability to be an intelligent customer and effective system integrator. A highly-respected automotive OEM nurtures deep understanding of technology and production; often through maintaining some production in house, dual-sourcing, and close working relationships. Because of this expertise, they know how much a component should cost. This helps to ensure that the supplier does not overprice – and does not underprice. The customer should not be spending more than what the part costs to make plus a fair margin for the supplier. If the supplier prices below cost, it will affect the supplier's ability to make a profit, the supplier's ability to survive and spend on innovations, and ultimately the quality and stability of the OEM's supply chain.

4.7 Chapter Summary

There exists a breadth of topics that should be addressed in the outsourcing decision, some of which are specific to the product and technology. If a firm focuses on reducing their financial burden and risk, they will tend toward outsourcing and partner arrangements. Traditional cost accounting also suggests short-term financial savings through outsourcing. However, an overreliance on outsourcing will introduce technological and competitive risk and lean accounting can demonstrate financial benefits to internal production. Integral airplane architecture suggests that the iterative and closely linked processes could be done most efficiently internally while also enhancing internal capabilities. Additionally, this period of rapid composites product and process innovation suggests that Boeing should concentrate learning.

5 Strategic Factors Affecting Outsourcing Decisions

There exists an extensive amount of literature on the make-buy decision. A few select examples of literature have been chosen to explain the importance of this decision and demonstrate potential ways to evaluate and make vertical integration decisions.

5.1 The Make-Buy Decision as a Core Competence

There are many types of skills that a corporation requires. Fine and Whitney explain why one of the most important skills is the decision-making skill to determine which skills to retain and what the company should or should not make. This is a capability that must be exercised repeatedly through time - especially during times of change. The two factors that must be managed are capability and capacity.

Manufacturing infrastructure is a foundational business element. On the hardware side, there are machine tools, robots, and fabrication & assembly systems. Software function can be split into design (CAD, CAM, CAE) and operations (scheduling, logistics, and database programs). Japanese companies are more involved in their infrastructure supply chain. They make a surprisingly large fraction of their own manufacturing equipment and design software. Toyota keeps it in house because it is non-decomposable – there are few well-defined interfaces to other elements. Toyota is "lean" on product supply, and "not lean" on infrastructure elements. They outsource near the top of the value chain while the US is opposite. US firms tend to focus on the end product. European manufacturers occupy middle ground by modifying much of their own hardware, but buy software. This difference is in part driven by philosophy. Japanese firms tend to hold the belief that they learn by doing and trying as opposed to buying manufacturing infrastructure. For example, Sony makes assembly equipment and Toshiba lithography equipment. Japanese industrial policy tends towards maintaining the nation's knowledge and technology base rather than producing a specific product. Product skills can follow process skills. In the case of the US consumer electronics industry, the lack of investment in process skills meant that their future designs were not able to take advantage of process advances in design like Japanese electronics (Fine & Whitney, Is the Make Buy Decision a Core Competence?, 1996).

Reasons for a firm to build its own equipment are to: gain more confidence in its level of process capability, create the ability to more heavily influence processes, easier production start-up, become a smarter customer, enhance understanding of required maintenance, retain firm-specific improvements, and neutralize instability of supplier expertise. Reasons to not build its own equipment are because it is costly (low ROI), potential diseconomies of scope, the insulation of internal suppliers from market forces, critical technology may become obsolete, it increases capital requirements, and a particular core competency could become a core rigidity.

Reasons to outsource part production are to access capability, increase manufacturing competitiveness, and access technology. Production should not be outsourced when the firm may disperse competitive knowledge and when production is visible to the customer or provides market differentiation.

Independent of whether a firm is outsourcing or building in-house, certain skills are required. They are the ability to: write clear and complete specifications, find or develop capable suppliers, and the ability to determine if goods meet specifications. Systems engineering plays a role in the make-buy decision. It is a critical skill to be able to translate customer needs into specifications and make the correct tradeoffs. Repeatedly, at multiple levels, teams must determine customer needs and break these down into supplier requirements. Different types of components are sourced in different ways. Easily decomposable parts are sourced to trusted suppliers with design goals rather than specific details. If a system is not as easily decomposed or if there is limited supplier experience or confidence in the supplier, then the OEM should take a more involved approach.

When a capability or skill is core, it is important that the firm is not dependent on capability. The firm must be able to differentiate between dependency for capacity and dependency for knowledge. The knowledge dependency chart shown in Figure 10 lists the skills from the most basic (top) to advanced (bottom).

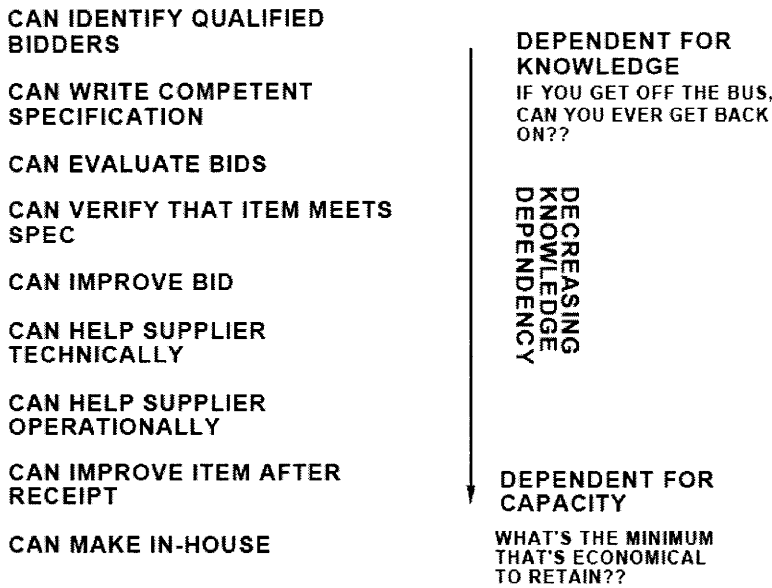


Figure 10: Knowledge Dependency

To manage risk, outsourcing choices should be influenced by the type of dependency and product architecture. Integral design architecture requires a top-down systems engineering design process. The product must be decomposed by defining boundaries between elements. The more easily decomposable items are the elements that should be outsourced. Product development and manufacturing infrastructure are most difficult to decompose because their tools and equipment are tightly linked to elements of the product, to key processes and learning activities in the firm, and to each other. This is the riskiest area to outsource.

The matrix of dependency in Figure 11 outlines what conditions are well-suited or ill-suited for outsourcing based on implications due to dependency and architecture. This is not a static analysis. The products in each quadrant may shift over time.

	DEPENDENT FOR KNOWLEDGE	DEPENDENT FOR CAPACITY
OUTSOURCED ITEM IS DECOMPOSABLE	**A POTENTIAL OUTSOURCING TRAP** YOUR PARTNERS COULD SUPPLANT YOU. THEY HAVE AS MUCH OR MORE KNOWLEDGE AND CAN OBTAIN THE SAME ELEMENTS YOU CAN.	**BEST OUTSOURCING OPPORTUNITY** YOU UNDERSTAND IT, YOU CAN PLUG IT INTO YOUR PROCESS OR PRODUCT, AND IT PROBABLY CAN BE OBTAINED FROM SEVERAL SOURCES. IT PROBABLY DOES NOT REPRESENT COMPETITIVE ADVANTAGE IN AND OF ITSELF. BUYING IT MEANS YOU SAVE ATTENTION TO PUT INTO AREAS WHERE YOU HAVE COMPETITIVE ADVANTAGE, SUCH AS INTEGRATING OTHER THINGS
OUTSOURCED ITEM IS INTEGRAL	**WORST OUTSOURCING SITUATION** YOU DON'T UNDERSTAND WHAT YOU ARE BUYING OR HOW TO INTEGRATE IT. THE RESULT COULD BE FAILURE SINCE YOU WILL SPEND SO MUCH TIME ON REWORK OR RETHINKING.	**CAN LIVE WITH OUTSOURCING** YOU KNOW HOW TO INTEGRATE THE ITEM SO YOU MAY RETAIN COMPETITIVE ADVANTAGE EVEN IF OTHERS HAVE ACCESS TO THE SAME ITEM.

Figure 11: Matrix of Dependency and Outsourcing

There is no one best outsourcing policy. A policy is suitable for a slice of time due to evolving technology advances, regulatory changes, and economic shifts. Because of this, the ability to consider and revisit the make buy decision may be the most important skill of all.

5.2 Core Competencies of the Corporation

C.K. Prahalad states that "Core competencies are the collective learning in the organization." They are the coordination, communication, and commitment to working across levels and functions of the organization. Core competencies must provide potential access to a variety of markets, make a significant contribution to customer perceived value, and be difficult for competitors to imitate. Building on these competencies, core products are the components or subassemblies that contribute value to end products. Dominance in these building blocks provides the power to shape the evolution of end products.

The successful corporation must determine what core competencies are most important for its future. The decision of core competence is tightly integrated with the overall strategy and drives other decisions regarding the organization, assets, and incentives. In the short run, a company's competitiveness is determined by its price and performance offer. As competitors converge on minimum performance for cost and quality, it becomes more important to develop additional capabilities over the long term. Future competitiveness comes from the ability to build core competencies that align the organization to spawn unanticipated new products more quickly and cost-effectively than its competitors.

A diversified corporation can be viewed as a tree (as depicted in Figure 12). By only looking at the leaves (end products), one would miss the underlying source of strength for the tree, the roots (core competencies). Those intertwined roots represent the combined knowledge of the firm; especially the coordination of technologies and production skills.

Figure 12: Diversified Corporation as Tree Metaphor

In contrast to a bank balance, competencies grow as they are applied and shared. They must be nourished and knowledge fades without use. Outsourcing can be a quick way to create a more competitive product, but it does not develop the organizational skills that sustain product leadership.

(Prahalad & Hamel, 1990)

5.3 Processes for Making Decisions

The framework detailed in Operations Strategy by Beckman and Rosenfield (2008) considers a few categories of factors. Those are the strategic (core capabilities, access to capabilities and capacity) which we have addressed, market factors such as the reliability and performance of suppliers, product factors such as architecture and technology differentiation, and economic (investment costs, design, production, and delivery costs, transaction costs) factors.

One process for finalizing the decision includes the following five steps.

1. Apply Core Capabilities Screen
2. Assess Industry Context and Identify Opportunities
3. Identify Alternatives
4. Assess the Alternatives and Select One
5. Implement

A similar approach was presented by Mroczkowski (2008), who created an important tool, the Decision Support Model (visualized in Figure 13), to help Boeing make more informed sourcing decisions. This model uses a fixed set of criteria and weightings to determine an aggregate score for each sourcing decision. The criteria are grouped into Strategic, Operational, Financial and Risk categories.

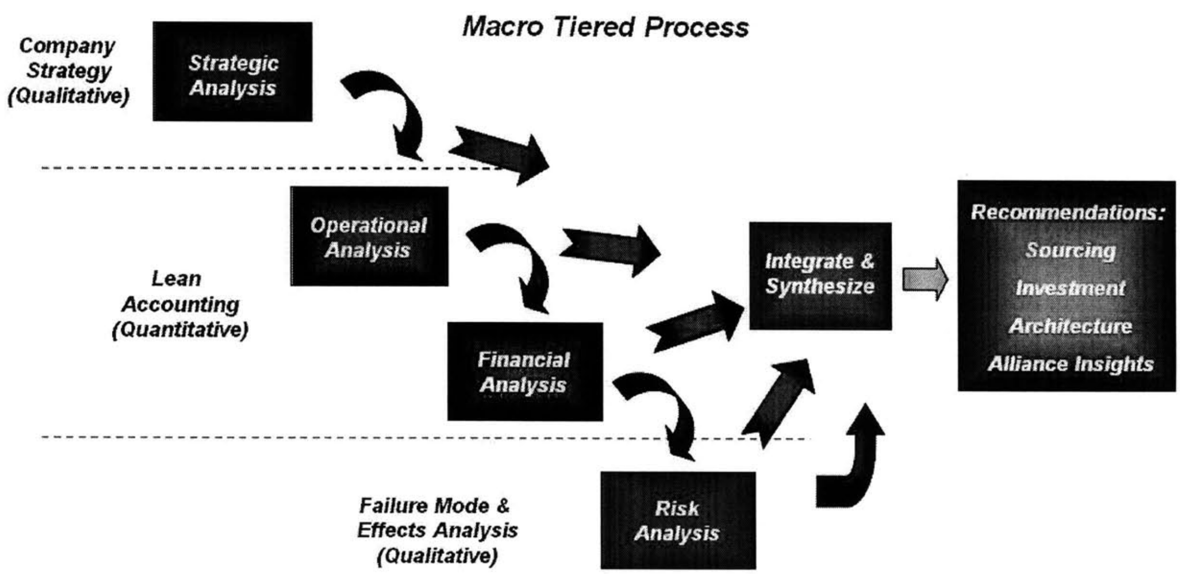


Figure 13: Integrated Decision Support Model (Mroczkowski, 2008)

The resultant score recommends whether Boeing should be inclined to vertically-integrate or outsource a particular work package. A supplier relationship type is recommended based on the score. It ranges from an arms-length relationship at the outsource end of the spectrum and progresses through supplier-managed inventory, long-term contracts, non-equity collaboration, equity investment, and an alliance/joint venture on the path towards full ownership.

This model was validated on two past vertical tail fin sourcing decisions. Driven by the application of carbon fiber reinforced plastic for the 777 tail fin, Boeing maintained internal production. In the case of the 737, the aluminum vertical tail fin with mature design and stable production volumes was outsourced. The complete list of decision factors and rating scale is listed in Appendix 5.

5.4 Chapter Summary

The vertical integration decision can be evaluated through the lens of multiple theories such as make-buy, core competencies, and decision frameworks. Research suggests that a dynamic analysis of strategic, market, product, and economic factors such as product architecture, dependency, and capabilities provide strong cues for outsourcing or vertical integration. In addition to the visible supply and cost factors, the firm must understand what competencies add value and where capabilities and architecture facilitate or hinder effective outsourcing.

6 Boeing Sourcing Processes

Boeing has created, documented, and applied a series of focused and wide-ranging sourcing processes. The company has consciously moved to a more integrated approach. The 787 Program sourcing decisions demonstrate that choices are influenced by more than a set of objective factors. They also reflect relationships and history.

6.1 Approaches within Boeing Commercial Airplanes

Over the years, Boeing has developed many sourcing processes. There are over 25 active documents pertaining to the multiple aspects of sourcing decisions. Some of these processes are optimized for individual stakeholders and consider a variety of topics like financial metrics, industrial participation, and work transfer.

One of the trends in sourcing was to outsource fabrication and assembly to satisfy work offsets. These work offset obligations were created with the sale of airplanes to foreign airlines. Oftentimes, these airlines are state-owned or continue to feel state influence. The trends of globalization meant that there was an increasing frequency to these work transfer requests.

In the early 2000's, Boeing recognized the need for a comprehensive and improved sourcing process that considered the many stakeholders using a longer-term enterprise-based approach. This led to the creation of the Supply Stream Policy Process. This gated process consists of two cross-functional teams that evaluate major decisions meeting pre-defined entrance criteria. This process is currently being used to source components for future airplane derivatives and to evaluate existing components that will be re-sourced. The Supply Stream process and how the proposed decision process will integrate into a portion of Supply Stream process are described in more detail in Chapter 7.2.

6.2 Study of the 787 Dreamliner Sourcing Decisions

The 787 program is Boeing's first new airplane program since the 777. Between those programs, Boeing had investigated development projects such as derivatives off the 747 as well as the Sonic Cruiser, a revolutionary high speed composite airplane concept.

One of the roots of the financial risk-sharing approach is the high development costs of the Sonic Cruiser. Due to composites usage and significant changes from typical designs, investment was estimated to be more than $10 billion, greater than required for a more traditional airplane program (Wallace, Boeing Sticking to Sonic Cruiser Plans, 2001). The company was not willing to "bet the company" on the new plane like they had done in the past like on the 747 program (Wallace, Sharing the Risk for 7E7, 2003). The large capital outlay and Boeing's 2016 vision of being a Large Scale Systems Integrator led them to move towards a financial risk-sharing model. Boeing also limits its financial risk by eliminating their internal exchange rate risk. Boeing purchases parts from suppliers and sells planes in USD without provisions for exchange rate fluctuations.

Eventually, the Sonic Cruiser concept was abandoned in favor of the 787 Dreamliner (originally named the 7E7). The 787 adopted a more traditional and less costly airplane architecture with development costs believed to be $7-10 billion (Wallace, Sharing the Risk for 7E7, 2003). Despite the reduced non-recurring cost, Boeing carried forward a similarly outsourced financial risk-sharing strategy. Thus, the 787 evolved to a more outsourced supplier structure when compared with previous airplane programs. The 787 program led its own sourcing decisions and placed the majority of the largest sections of the airplane with outside partners.

Due to the advanced nature of the 787 product and manufacturing process, it required sophisticated composites and aerospace expertise. In addition, few suppliers had enough financial depth to be financial risk-sharing partners. Because of these factors, none of the major chunks were sourced to low cost regions. All the major 787 partners had previous relationships in prior airplane programs and development contracts and they were selected from the Sonic Cruiser development partners.

Japan Aircraft Industries (JAI) was awarded responsibility for the wings and a section of the fuselage. Alenia was awarded the center fuselage and horizontal stabilizers, and Vought was to build the aft fuselage. The most complex piece of fuselage, flight deck and some of the control surfaces of the wing, were retained internally at the Wichita, Tulsa, and Australia fabrication divisions. As of late 2003, Boeing planned to produce 35% of the airframe internally (Ranson, 2003). However, the subsequent divesture of the Wichita and Tulsa divisions to Onex (Spirit AeroSystems) meant that Boeing was no longer producing any major section of the aircraft. The largest system being produced internally is the vertical tail fin being produced by the Fabrication Division in

Fredrickson, WA. Figure 14 shows a summary of the current suppliers and build locations for the initial Boeing 787. Table 7 shows a history of the sourcing decisions on the Sonic Cruiser and 787.

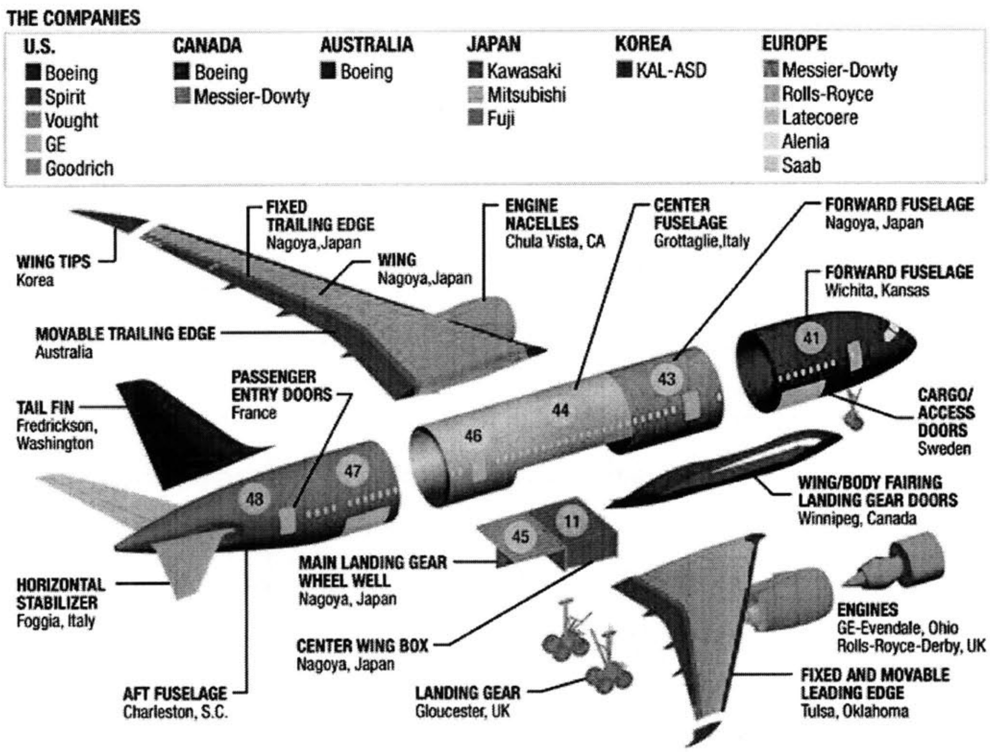


Figure 14: Boeing 787 Sourcing Partners by Section (Bair, 2007)

Sonic Cruiser Development Partner Announcements

Jan 2002	Japan Aircraft Industries
Feb 2002	Alenia Aeronautica
Feb 2002	Vought Aircraft Industries
Apr 2002	Wichita (now Spirit Aerosystems)
Apr 2002	Hawker de Havilland
Jul 2002	Fischer Advanced Composite Components (FACC) AG
Jul 2002	GKN
Jul 2002	Stork Fokker
Sep 2002	Winnipeg

7E7 Partner Announcements and Fabrication Divesture

Jun 2003	Japan Aircraft Industries
Jun 2003	Alenia Aeronautica
Jun 2003	Vought Aircraft Industries
Jun 2005	Wichita and Tulsa fabrication divisions divested

Table 7: Sonic Cruiser and 7E7 Sourcing Developments (News Releases, 2009)

Market access is an important factor in many sourcing decisions. This is less due to an effort to understand local customers and more based on generating sales as an incentive for the airline and associated government. This tends to be more successful in some countries more than others. One successful example for Boeing is the strong relationship with Japanese airlines. Overall, Boeing holds over to an 80% market share for the Japanese airlines (Suga & Rothman, 2007). Perhaps in part because of Boeing's relationship with JAI and the placement of significant work in the alliance, the 787 launch customer, All Nippon Airways (ANA), and JAL International have placed a combined 85 orders for the 787. Unfortunately, the work placed with Alenia has not resulted in any orders from Italian airlines.

6.3 Chapter Summary

Boeing has developed a series of focused and wide-ranging sourcing processes including the integrated Supply Stream process. While these individual processes are standardized, the exact application of sourcing procedures is not. The 787 Program stayed deeply involved in their sourcing decisions, drew on a team of trusted partners, and progressed on its journey of becoming a Large Scale Systems Integrator.

7 Discussion-based Sourcing Process

This chapter introduces considerations that reinforced the proposed strategy development process to be discussion-based. Then, its integration with Boeing's Supply Stream is discussed. The chapter closes with an overview of the strategy development process and an explanation of its major process steps.

7.1 Considerations in Deciding how to Decide

Different strategies drive different supply chain architectures. On one extreme, a company like Cisco outsources the vast majority of production and focuses on product design and the management of its supply chain. Therefore, their sourcing decisions place more attention on the evaluation of relationship types and which contract manufacturers and suppliers to work with. In a more common scenario, most companies will have a mix of internally and externally-produced parts which drives the need for a vertical integration decision process.

The Vroom-Yetton model (Vroom, 2007) shows the importance of discussion and levels of decisions based on what is most important. The decision can be manager or team-centered. Some of the factors affected by decision process are decision quality, implementation, time, and employee development. As shown in Figure 15, there is a range of decision-making types ranging from the leader deciding to the leader delegating the decision to his or her team. The ideal choice depends on characteristics of the decision and whether a time-driven or development-driven model is used.

Decide	Consult	Facilitate	Delegate

Individual, time-focused ⟶ **Team, development-focused**

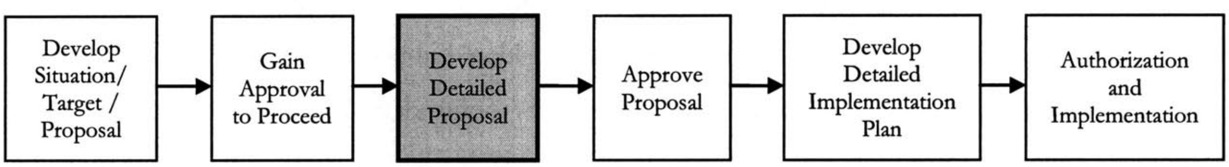
Figure 15: Range of Decision Types

The development-driven model emphasizes long-term employee development and the time-driven model optimizes for the fastest high-quality decision. In both models, decisions with high significance and importance of commitment mean that the decision should be made in a team environment.

While the Vroom-Yetton framework is important for planning an appropriate means of making a decision, others have empirically demonstrated that constructive controversy can be an even more important factor for successful decision outcomes. Constructive dialogue of opposing opinions has been shown to be a positive type of interaction. Open discussion of opposing views, can help avoid the risk of groupthink. For this reason, the proposed process should bring together teams with different backgrounds and functions (Tjosvold & Wedley, 1985).

7.2 Discussion-based Process Integration with Boeing Sourcing Process

The Supply Stream Process, which follows the simplified flow diagram in Figure 16, is used at BCA for decisions with large financial, organizational, or strategic impact. Typically, the Supply Stream Process Team (SSPT) will evaluate decisions below specified thresholds. Decisions with greater impact that exceed the SSPT thresholds must be approved by the Supply Stream Policy Board (SSPB). Many organizations are represented in these teams and the SSPB members are the highest-level executives for their respective area. Minor and non-strategic sourcing decisions are completed by the individual buyer in the Supplier Management organization who completes a comprehensive checklist called the procurement board. Once approvals are completed in the appropriate forum (SSPB, SSPT, or procurement board), the sourcing decision is made.



Team Members:

Airplane Programs	Fabrication	People / Union Relations
Airplane Production	Finance	Propulsion Systems
BCA Work Movement	Global Strategy	Renton Programs
CAS	IT	Sales
Engineering	Manufacturing & Quality	Supplier Management

Figure 16: Simplified Supply Stream Process Flow with list of Team Members

Since Boeing already has a structure for a cross-functional sourcing process, it is prudent to work within the existing framework to implement the discussion-based strategy development process (See highlighted box in Figure 16) described in Sections 7.3 to 7.5. It is important to build off the existing teams and build on the stability of the existing process – a process that can be used for both vertical integration and outsourcing decisions. The discussion-based strategy development process is being proposed to develop a detailed sourcing decision and proposal. Although a sample set of criteria based on many of the strategic, technology, and financial factors in Chapters 4 and 5 are proposed in this work, the ultimate goal is for senior BCA leadership to select their own criteria to begin the process and to revisit the criteria and weightings on a regular basis.

7.3 Strategy Development

During initial project research, this approach was compared with a strategic flow chart, list of weighted criteria, and a principle-based approach. Strengths of the flow-chart process are the ability to follow the logic flow and a consistent way of making decisions. Use of weighted criteria can be time efficient, and a principle-based approach enhances alignment. Even though the discussion-based strategy development process requires the involvement of a larger team and can be more time-consuming than other approaches, its benefits make this the more desirable process for complex systems and important work packages.

The advantage of a discussion-based strategy development process that the other decision processes do not have is the structured method of operationalizing comparisons of relative importance to create weightings. Not only does this turn the negotiation away from the numbers or weightings, it offers a degree of transparency into what factors are considered important and how the weightings were derived. In addition, it is an important development tool to develop the strategic thinking of teams of employees. Not only does this provide a forum for leadership to discuss strategy on a regular basis, it infuses the latest thinking into the rest of the organization and develops expertise in future generations of leaders.

The proposed strategy development process shown in Figure 17 is used to develop detailed proposals for new and existing vertical integration and work placement decisions. This structured approach ensures the usage of standard work. It also makes the decisions easier to follow as the Supply Stream teams will be accustomed to the common format. In addition, it ensures that a common set of factors are considered.

The first step is for a cross-functional team of stakeholders to jointly develop a list of decision criteria. Previous participation in discussion-based workshops demonstrated the difficulty in maintaining decision factor consistency. The variety of teams and workshop decisions uncovered varying criteria and potential areas for refinement. With differing goals and short-term focus, there was limited factor overlap from one workshop to the next. To reduce variation and align with long-term corporate strategy, the criteria should be defined by the airplane leadership team in Steps 1 and 2, and a set of core criteria should be common from one decision to the next. The sourcing proposal constraints and required decisions developed in Step 3 are then used in Step 4 to create strategy tables which facilitate a common, visual representation of the different approaches that could be pursued to satisfy a sourcing decision. Step 5 is for the team to evaluate those approaches against the decision criteria which creates a grade for each approach. Once, the results are understood, the team develops a hybrid approach in Step 6 to optimize the strengths and minimize the weaknesses of the approaches evaluated in the previous step. Once satisfied with the hybrid proposal, the team begins collaborating with other stakeholders to develop a detailed implementation plan. A few of the selected steps will be discussed in greater detail in the following subsections and in Chapter 8: 737-Replacement Future Composite Wing Case Study.

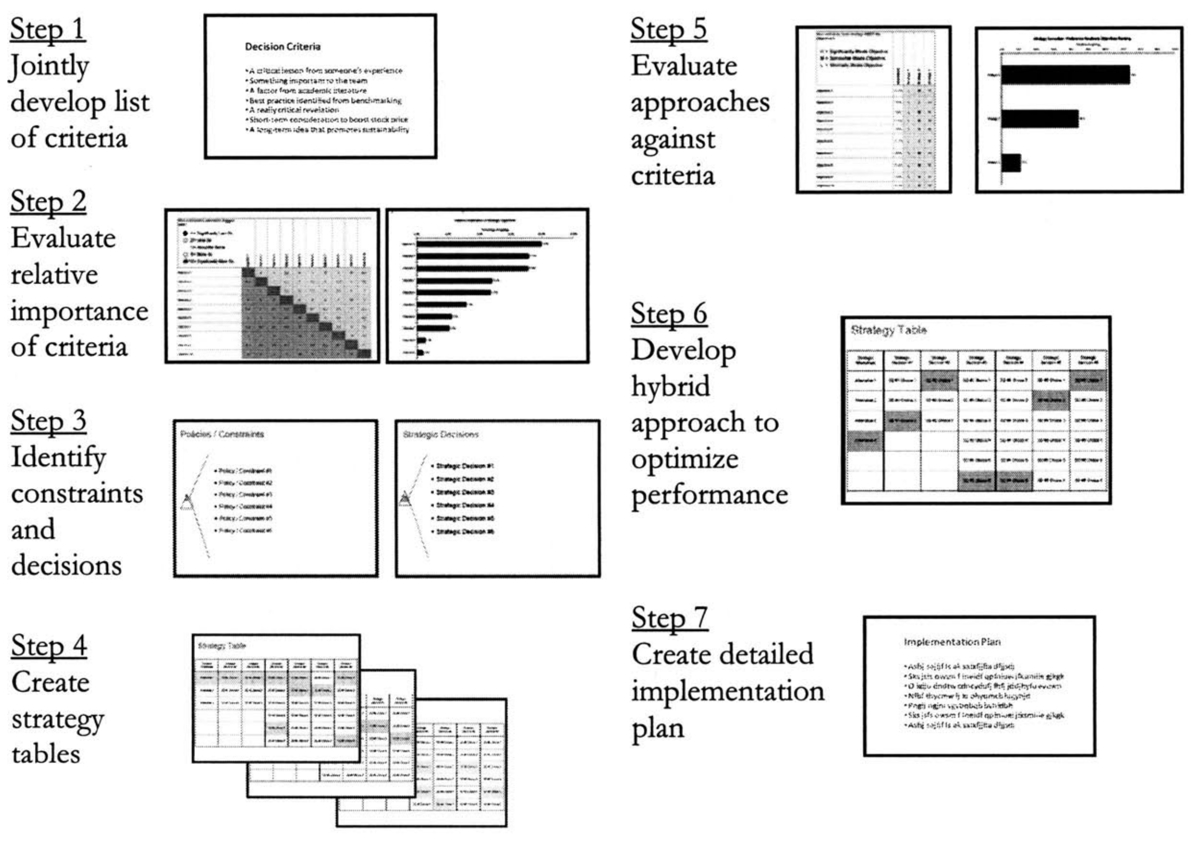


Figure 17: Strategy Development Process (Leonhardi, 2008)

A diverse team of subject matter experts was involved in trialing the process. The team had been involved in multiple airplane programs and ranged from new hires to veterans with over three decades of experience. Multiple functions across the organization were represented.

- 787 Program	- Airplane Programs
- Supplier Management Program Management	- BCA Core Program Management
- Supplier Management Strategy	- Global Strategy
- New Airplane Product Development Operations	- Business Development
- Product Strategy and Development	- Fabrication
- Engineering and Manufacturing	- Lifecycle Product Team
- Future Production System	- Estimating and Pricing

Table 8: Organizational Functions Involved in Process Development

A standard set of decision factors will be proposed and evaluated by the BCA senior leadership team. The factors I propose are:

- Enhancing Global Production System Capabilities
- Minimizing Risk to airplane program and Boeing
- Recurring Cost
- Ensure Long-term flexibility and adaptability
- Product Architecture Integrality
- Protecting Boeing Competitive Advantage
- Flow/Logistics
- Increase Sales
- Boeing non-recurring cost

These factors are based on multiple discussions and workshops run within Boeing. Where gaps were determined between research and empirically-defined factors, additional factors were substituted. Product architecture was added as a decision criterion due to its importance to supply chain architecture. The criterion for minimizing disruption to current programs was removed because it was evaluated as lower importance during trial workshops and is partially captured by the "Minimizing Risk to airplane program and Boeing" factor. This set of decision criteria is proposed for the scenario of making a sourcing decision on a new product.

This set of standard criteria should be reviewed on at least an annual basis and when changes take place that affect the corporate strategy. This consistency provides stability in the sourcing process. Additional factors can be justified in addition to the 9 core criteria to tailor the decision process for individual work packages. Up to two more factors allows sufficient change to the criteria and weightings while limiting the external impact on the core values used to create this process.

7.4 Relative Importance Matrices

The same list of decision criteria is listed on the leftmost column and uppermost row of cells in the relative importance matrix of Figure 18. Each colored box represents a pair-wise comparison of one decision criterion against another. Since the darker gray diagonal boxes compare the same criteria against themselves, they are omitted.

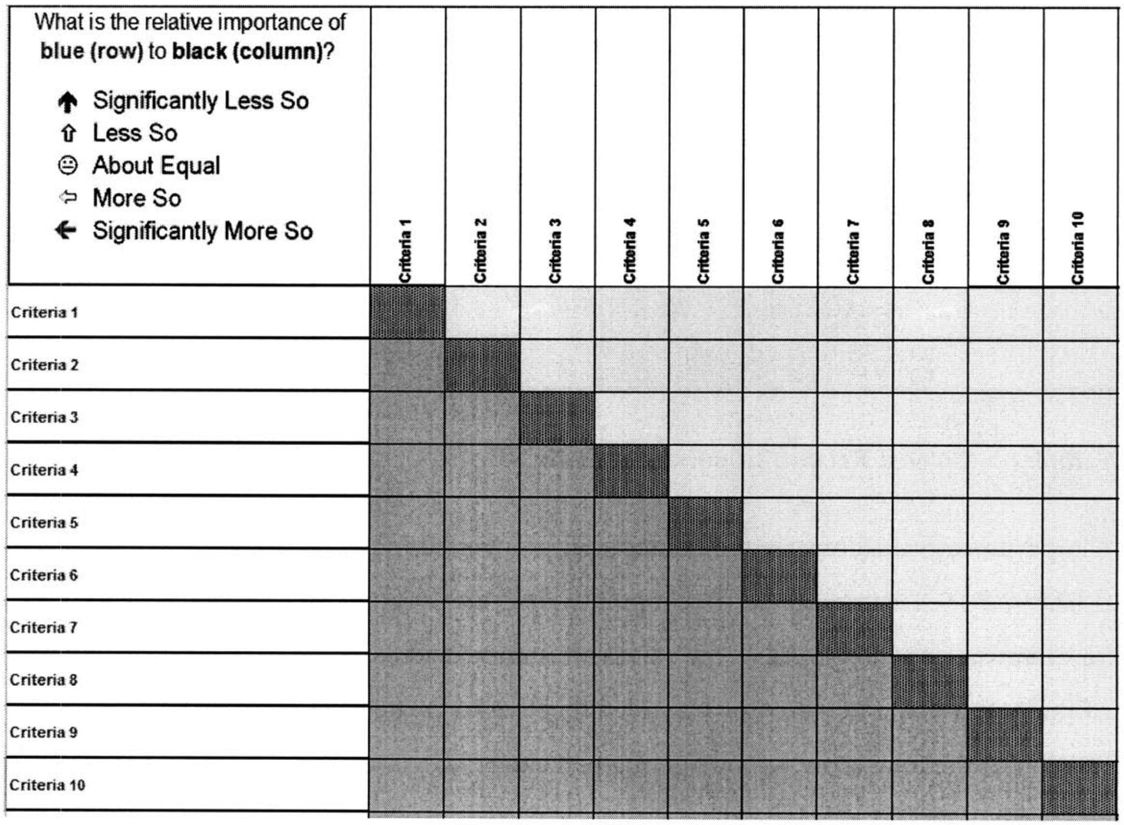


Figure 18: Blank Relative Importance Matrix

When making comparisons, a criterion can be equally, more, or significantly more important than the other criterion. Since the same comparisons are made in the upper right (yellow) and lower left (light gray) set of cells, only the upper right (yellow) group of cells needs to be completed. The corresponding lower left (light gray) cells are automatically populated. Each entry is evaluated on an individual basis and debated by the collective team. Since people have different backgrounds and incentives, there is not complete agreement for every comparison. Each cell is completed once a consensus is reached.

What is the relative importance of **blue (row)** to **black (column)**?

- ⬆ Significantly Less So
- ⇧ Less So
- 😐 About Equal
- ⇦ More So
- ⬅ Significantly More So

	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Criteria 6	Criteria 7	Criteria 8	Criteria 9	Criteria 10
Criteria 1		⬆	⇧	😐	⇦	😐	⇧	😐	⇧	⇧
Criteria 2	⬅		😐	⇦	😐	⬅	⇦	⇦	😐	😐
Criteria 3	⇦	😐		⇧	⇦	😐	⇧	😐	⇦	😐
Criteria 4	😐	⇧	⇦		⇦	⇧	⇦	😐	😐	😐
Criteria 5	⇧	😐	⇧	⇧		😐	⇧	⇦	⇧	⬆
Criteria 6	😐	⬆	😐	⇦	😐		⇧	😐	⇦	⇧
Criteria 7	⇦	⇧	⇦	⇧	⇦	⇦		⇦	⇧	😐
Criteria 8	😐	⇧	😐	😐	⇧	😐	⇧		⇧	⇧
Criteria 9	⇦	😐	⇧	😐	⇦	⇧	⇦	⇦		⇦
Criteria 10	⇦	😐	😐	😐	⬅	⇦	😐	⇦	⇧	

Figure 19: Sample Completed Relative Importance Matrix

The relative importance evaluations are then numerically converted to the percentage weightings summing to 100%. For each criterion, different point values are assigned for each box based on the multiplier for each type of symbol. All of the values are summed across the row to create a criterion score. All of these summed criteria scores are added together to create a grand total. Each criterion's fraction of the total score is its weighting percentage.

7.5 Subsequent Process Steps

In Step 3 of the Strategy Development Process introduced in Figure 17, constraints and strategic decisions are defined that will shape the sourcing proposals (organized into strategy tables) in Step 4. These sourcing proposals are created based on what key strategies must be determined for the particular decision scenario and organized into strategy tables. These tables are used to ground the team in a common understanding of each sourcing proposal when they are scored in a separate scoring matrix. Those scores and weightings are combined in order to determine strategy scores. These steps are illustrated in the 737 Replacement wing study in Chapter 8.

Final steps are to combine the best elements of each strategy to create a more optimal approach. With the strategy confirmed, the team then begins the important step of creating an implementation plan to be brought forward for approval.

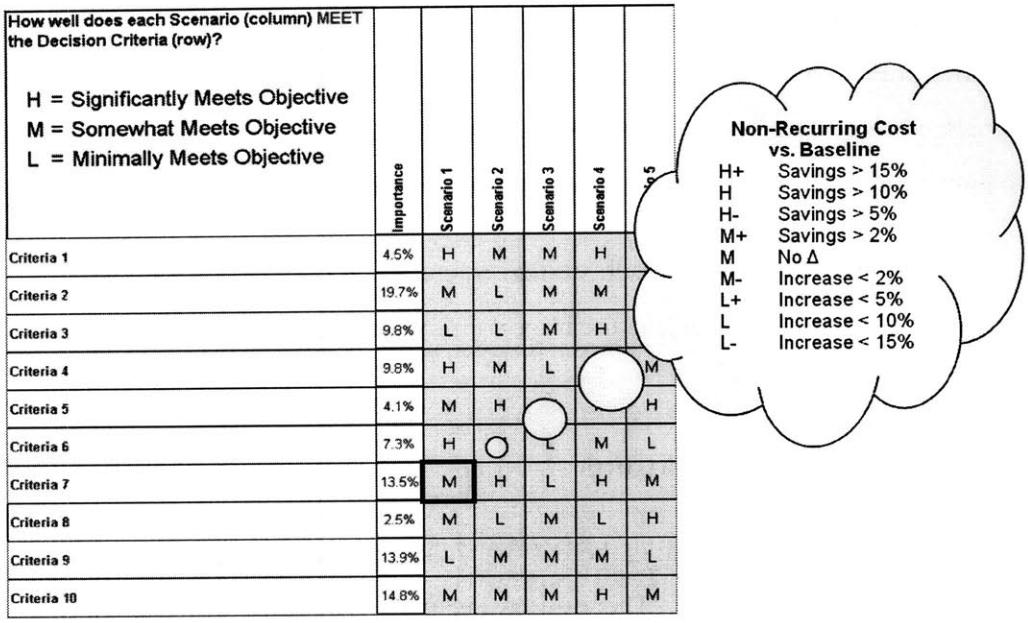
7.6 Add-ins for Performance Evaluation

In order to keep the process dynamic and flexible, there is the ability to plug in more detailed evaluation criteria as the process board sees fit. This process maintains the capability to upgrade the evaluation precision as Boeing continuously develops its measurement techniques.

The open-source approach maintains flexibility for teams to implement the latest methods of evaluation. This model of operation and decision making allows concurrent input of different agendas, approaches and priorities, and differs from the more closed, centralized models of development. It is a more modular and collaborative approach.

The current evaluation process only differentiates between three relative levels of performance. This process would be able to accommodate many types of changes. Add-ins can be developed offline and "plugged in" after Supply Stream Policy Board approval. Some areas could be:

- Recurring cost using comparative value stream cost
- Modularity-Integrality analysis



	Importance	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Criteria 1	4.5%	H	M	M	H	[illegible]
Criteria 2	19.7%	M	L	M	M	[illegible]
Criteria 3	9.8%	L	L	M	H	[illegible]
Criteria 4	9.8%	H	M	L	[illegible]	M
Criteria 5	4.1%	M	H	[illegible]	[illegible]	H
Criteria 6	7.3%	H	[illegible]	L	M	L
Criteria 7	13.5%	M	H	L	H	M
Criteria 8	2.5%	M	L	M	L	H
Criteria 9	13.9%	L	M	M	M	L
Criteria 10	14.8%	M	M	M	H	M

Figure 20: Sample Evaluation Matrix Upgrade

7.7 Chapter Summary

A discussion-based decision-making process can be structured to make integrated decisions. Constructive dialogue drives balanced decisions by allowing several subject matter experts to share points of view and generate consensus. With the core set of criteria and weightings influenced by leadership vision, there is improved consistency and transparency throughout the process. This structured approach is transparent and has documentation of the strategy, data, thought process, and constraints inherent in the process.

8 737-Replacement Composite Wing Case Study

This chapter begins by describing an airplane wing and composite wing production. Then, the composite airplane wing scenario is used to demonstrate the discussion-based sourcing process from the previous chapter. This section concludes with sample results and recommendations for design and production.

8.1 Description of an Outboard Airplane Wing

This case discusses the composite airplane wing for the next generation single-aisle 737-replacement airplane. The airplane wing is one of the most complex parts of an airplane. It must provide lift, support the airplane loads, as well as store the plane's fuel. Boeing's wings have typically been designed with a center section and two outboard wings with a wing-to-body joint as part of the designed system. The architecture of a wing has been optimized to have load bearing skin, and sets of spars, ribs, and stringers to efficiently add stiffness to the main wing box. For the purposes of this study, the sourcing proposal will focus on the main wing box and the critical joints. It treats the mating components (ie. engines, landing gear, and control surfaces) as separate.

The wing to body joint is a very critical and complex interface due to its critical safety nature as well as transferring mechanical load, information, material, and electricity. These demanding functional requirements cause this joint to be highly integral and difficult to assemble. Prior to the 787, Boeing built its own wings. Figure 21 provides a visual representation of the wing architecture, shows the location of the wing to body joint, and the major structural components of a typical airplane main wing box.

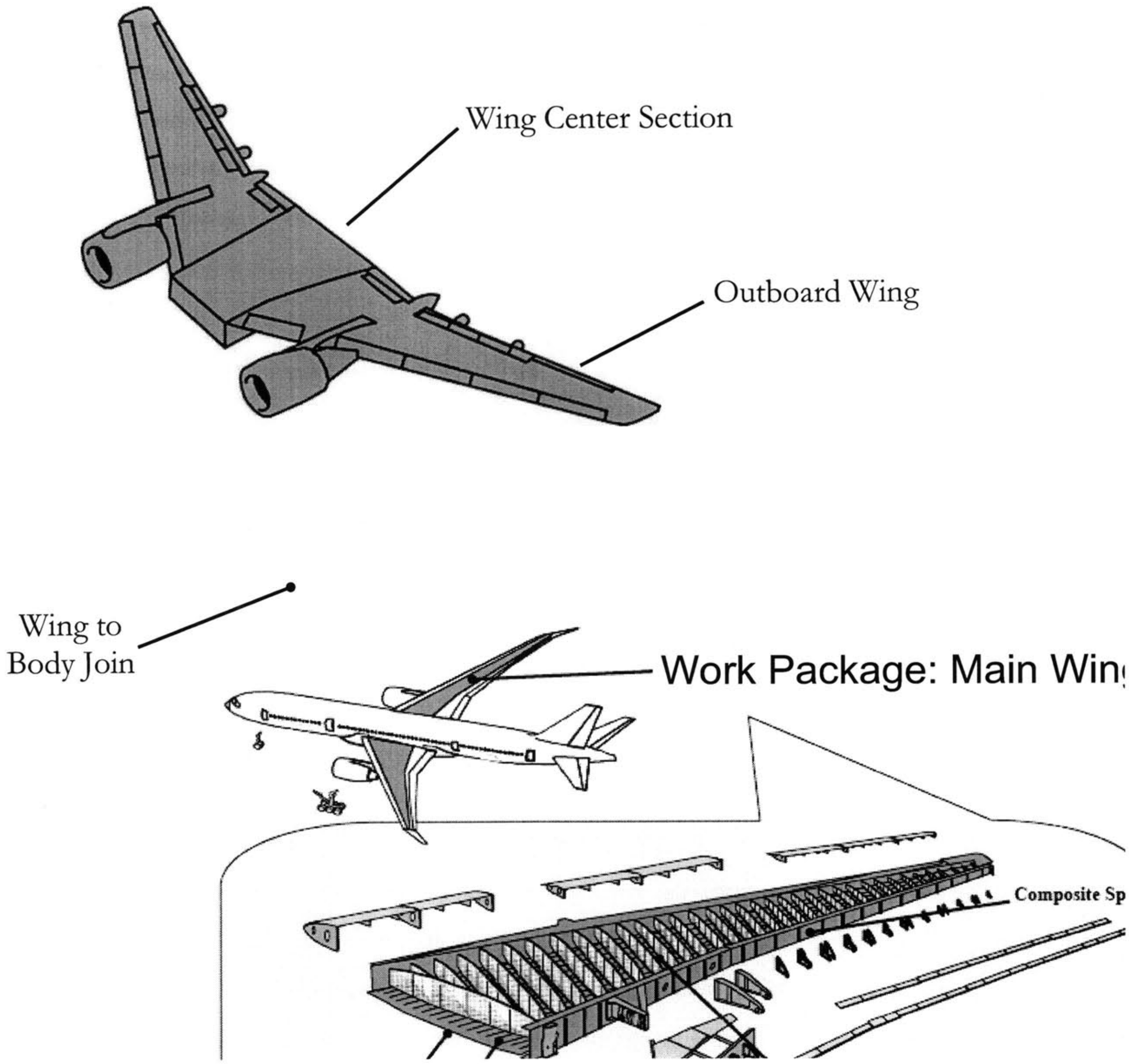


Figure 21: Visual Depiction of Main Wing Box Work Package (Boeing, 2008)

8.2 Composite Wing Production

Composite components of an airplane wing are made using a variety of processes and materials. Most components are fabricated from pre-preg unidirectional tape and some are made using fabric or honeycomb. The airplane upper and lower skins are fabricated with the use of composite tape-laying machines. The machines apply plies of pre-preg tape which are placed in the correct orientation and cut to size. The stringers, spars, and ribs are produced in different processes that also employ special forming techniques. The separate constructions are cured in an autoclave.

In a wing, multiple types of joining processes are employed. Separate composite parts can be bonded through the co-cure, co-bond, and secondary bond processes. On the 787 program, the cured stringers are co-bonded to the wing skin. Fasteners are still employed for an extra margin of safety against crack propagation. Fasteners are also the primary joining method for most other components. Figure 22 shows some of the major composite wing production process steps.

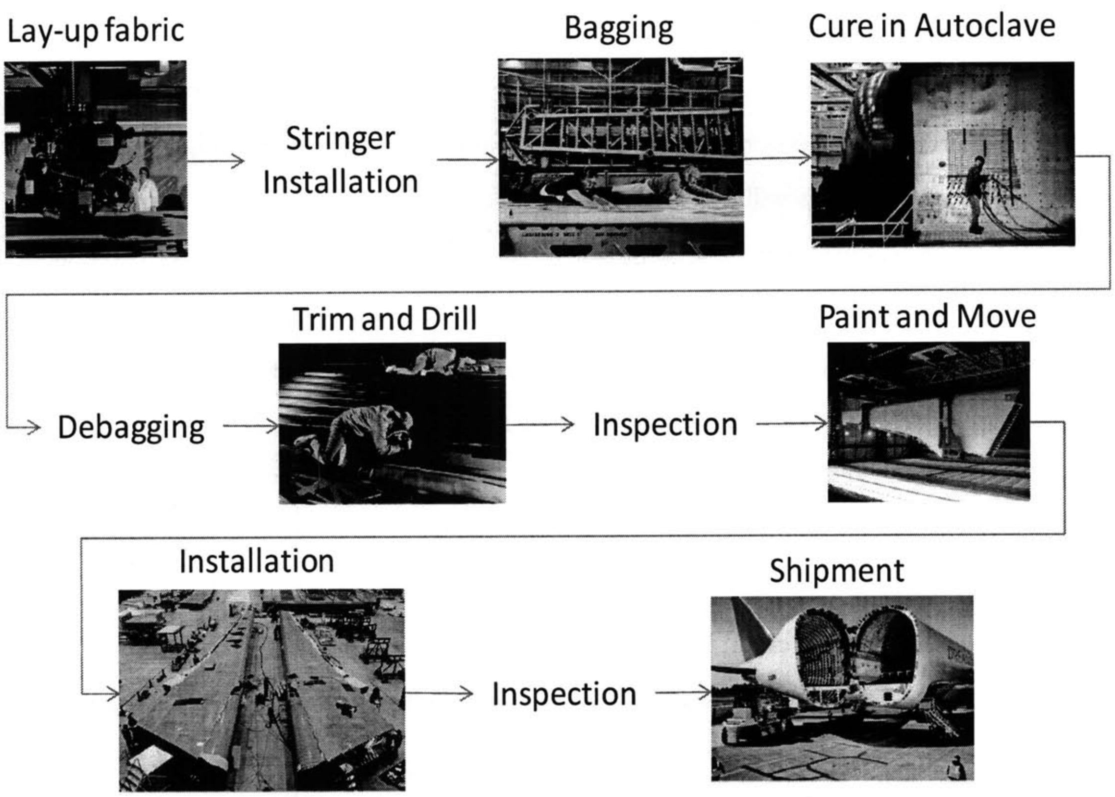


Figure 22: Composite Wing Production Process (Segal & Copeland, 2008) (Ostrower, 2008)

Wings have typically been built in large jigs sometimes referred to as majors. Multiple sets of tools were used to assemble the wing structure and systems. Teams would perform separate sets of operations as they rotated from one set of wings to the next. 787 wing production moves to a new process and other lean manufacturing models are under development. This study assumes that the build process will be the same independent of the location where the wing is built.

8.3 Assumptions

Due to the open-ended nature of this study, it was necessary to make assumptions to bound the problem and manage the scope. While these assumptions were made to simulate a realistic scenario, they do not represent Boeing's official views, and some details may have been changed to protect Boeing's future strategies.

- Entry Into Service timing will not be negatively impacted by this decision.
- The airplane will be built at a single final assembly site in the Puget Sound region.
- Common architecture design / build guides created and maintained by Boeing (Requirements & objectives).
- Recommendations must be vetted with the Supply Stream Policy Board (SSPB).
- The organization that releases the design assumes the responsibility for the quality of the design; All involved parties will meet FAA requirements.
- Boeing will abide by current Import & Export policies.
- The high-level wing architecture will remain consistent with the 787 design.
- Fabrication and assembly techniques will be similar to the 787 process.
- External suppliers are capable and willing to share non-recurring costs.
- Production volume will reflect the Boeing Current Market Outlook.
- Global work offsets will not be as critical for this program due to the customer makeup for the single aisle airplane market.
- No Industrial Participation credit for supplier or JV production in US.
- Carbon footprint: assume the same manufacturing processes and energy sources anywhere in the world.
- No commitments to suppliers for development work on cancelled airplane programs.

Alternative assumptions were considered, but they were rejected based on proprietary information, the need to conform to publicly-stated forecasts, or low likelihood as subjectively determined by subject matter experts.

8.4 Basic Strategies

Evaluating the potential 737-replacement future composite wing design and production requires the careful grading of distinct proposals. This case considers the design & integration, fabrication & assembly, and the program management of a composite airplane wing. For this case, three distinct strategies will be discussed: a vertically-integrated approach, a vertically-disintegrated large-scale systems integrator approach, and a low-cost approach. The first two scenarios are considered at opposite ends of the vertical-integration spectrum and bound the problem. The third approach combines multiple elements of each in a way that is expected to generate the lowest overall program cost for this individual program.

These three approaches are organized into strategy tables that address the identified constraints and strategic decisions to be made (from steps 3 and 4 of the Strategy Development Process introduced in Figure 17). The strategic decisions specify how the sourcing proposal deals with aspects of important issues including, but not limited to: design, build, production location, and certification. The strategy tables and plots from Figure 23 illustrate the differences between these distinct approaches.

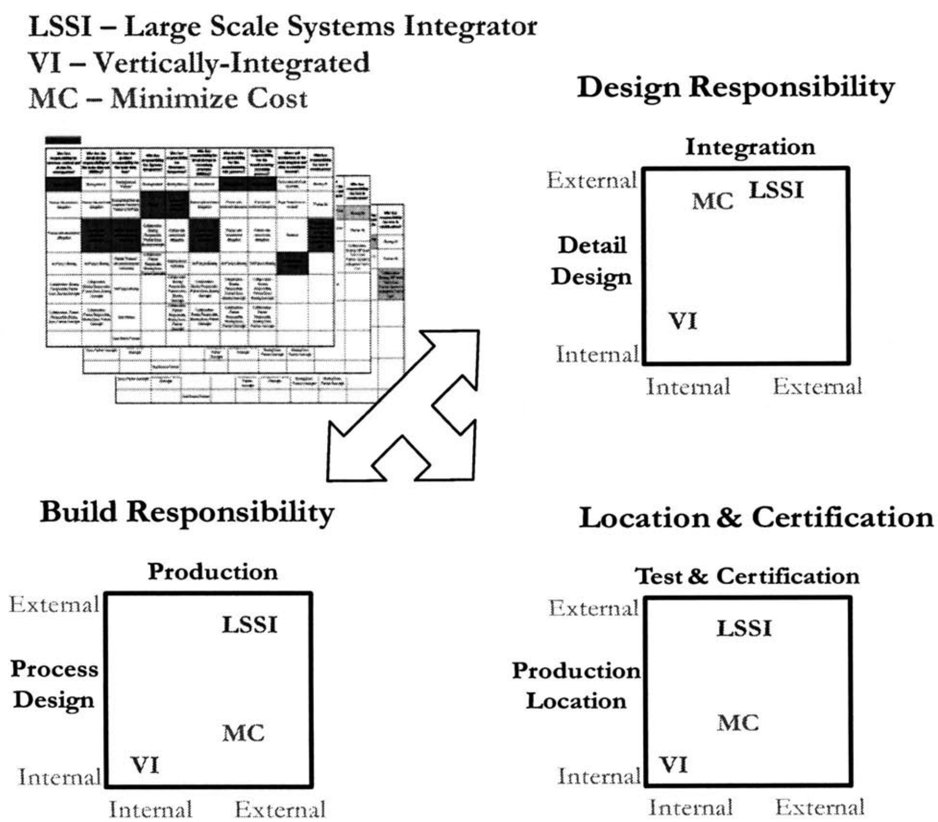


Figure 23: Selected Composite Wing Strategies

8.5 Criteria, Importance, Weightings, and Scores

A team of subject matter experts (representing the organizations listed in Table 8) took on the role of the senior Airplane Leadership Team to represent multiple functions and programs. The long-term vision from this workshop acted as a starting point for the core set of decision criteria and weightings that provide process stability from one decision to the next.

Relevant criteria must be used to make decisions. In addition, each criterion must be considered with respect to its relative importance. A list of potential criteria were brainstormed and compiled from multiple resources. In order to make the decision process manageable, the team targeted a list of ten or fewer decision criteria. There was a great deal of deliberation to select and group criteria in a manner where they would have little overlap and be of relatively equal standing (versus having high-level strategies being compared with specific tactics). The results are:

- Recurring Cost (flow, supply chain architecture, overhead, reduced supplier investment)
- Boeing Non-recurring Cost (Facilities, tooling, development)
- Minimize Disruption to Current Programs (Stability, supplier market)
- Increase/Use Boeing Knowledge Management to Enhance Global Production System Capabilities
- Protect Boeing Competitive Advantage (innovate faster, intellectual property management)
- Increase Sales (Global Strategy)
- Minimize Risk to Program and BCA (Timing, performance, cost)
- Ensure Long-term Flexibility and Adaptability (Aligned incentives for C.I.)
- Flow/Logistics (Operate with lean principles, minimize all types of transactions)

This group of factors is very similar to the criteria listed in Section 7.3. The main difference is that these criteria include "Minimize Disruption to Current Programs" and do not include "Product Architecture Integrality".

A blank chart with the selected criteria was used to evaluate relative importance. Each of the criteria was listed on the left-most column and top row. Each pair-wise comparison was evaluated by the cross-functional team until a consensus was reached. One criterion can be evaluated as significantly less important, less important, approximately equal, more important, or significantly more important than the other criterion. These were selected using individual drop down boxes built into the yellow spreadsheet cells forming the upper-left triangle. The symbols were automatically updated in the corresponding gray cells. The comparative rankings were reviewed again prior to viewing the results.

Hypothetical data is provided as an example to visualize the process.
Actual categories and evaluations may differ.

What is the relative importance of blue (row) to black (column)?

- ⬆ Significantly Less So
- ⇧ Less So
- 😐 About Equal
- ⇦ More So
- ⬅ Significantly More So

	Recurring Cost (flow, SCA, overhead, reduced supplier investment)	Boeing Non-recurring Cost (Facilities, tooling, development)	Minimize Disruption to Current Programs (Stability, supplier market)	Increase/Use Boeing KM to Enhance Global Prod System Capabilities	Protect Boeing Competitive Adv. (innovate faster, Int. Prop. mgmt)	Increase Sales (Global Strategy)	Minimize Risk to Program and BCA (Timing, performance, cost)	Ensure Long-term Flexibility and Adaptability (Align incentives for C.I.)	Flow/Logistics (Operate with lean principles, min. all transactions)
Recurring Cost (flow, SCA, overhead, reduced supplier investment)		⇦	⇦	⇧	😐	⇦	😐	😐	⇦
Boeing Non-recurring Cost (Facilities, tooling, development)	⇧		⇦	⇧	⇧	⇧	⇧	⇧	⇧
Minimize Disruption to Current Programs (Stability, supplier market)	⇧	⇧		⇧	😐	⇧	⇧	⇧	⇧
Increase/Use Boeing KM to Enhance Global Prod System Capabilities	⇦	⇦	⇦		😐	⇦	😐	⇦	⇦
Protect Boeing Competitive Adv. (innovate faster, Int. Prop. mgmt)	😐	⇦	😐	😐		😐	😐	⇦	⇦
Increase Sales (Global Strategy)	⇧	⇦	⇦	⇧	😐		😐	⇧	⇧
Minimize Risk to Program and BCA (Timing, performance, cost)	😐	⇦	⇦	😐	😐	😐		⇦	⇦
Ensure Long-term Flexibility and Adaptability (Align incentives for C.I.)	😐	⇦	⇦	⇧	⇧	⇦	⇧		⇦
Flow/Logistics (Operate with lean principles, min. all transactions)	⇧	⇦	⇦	⇧	⇧	⇦	⇧	⇧	

Figure 24: 737-Replacement Composite Wing Relative Importance Matrix

A sample of the reasoning behind the discussion rankings is listed below:

- Learning by doing and increasing global production systems capability (through Knowledge Management) is considered to be as important or more important than every other factor.
- Cost is very important. Airlines purchasing single-aisle airplanes value purchase price, fuel efficiency, and maintenance costs as the three most critical factors in making their purchasing decisions.
- Boeing recurring costs include partner non-recurring costs. Reducing Boeing's non-recurring costs increases supply base non-recurring cost and Boeing recurring cost.
- Boeing has demonstrated an ability to handle disruption to existing programs.
- It is more important to minimize risk on new programs versus existing programs

- Long-term flexibility and aligned incentives between Boeing and its source results in lower long-term costs and significant operational improvements.
- While growing more balanced over time, the United States airlines continue to be by far the largest single country source of 737 customers. This reduces the relative incentives for global sourcing when compared with other programs. Details can be found in Appendix 5.

The relative importance evaluations were numerically converted to the percentage weightings below.

Hypothetical data is provided as an example to visualize the process.
Actual categories and weightings may differ.

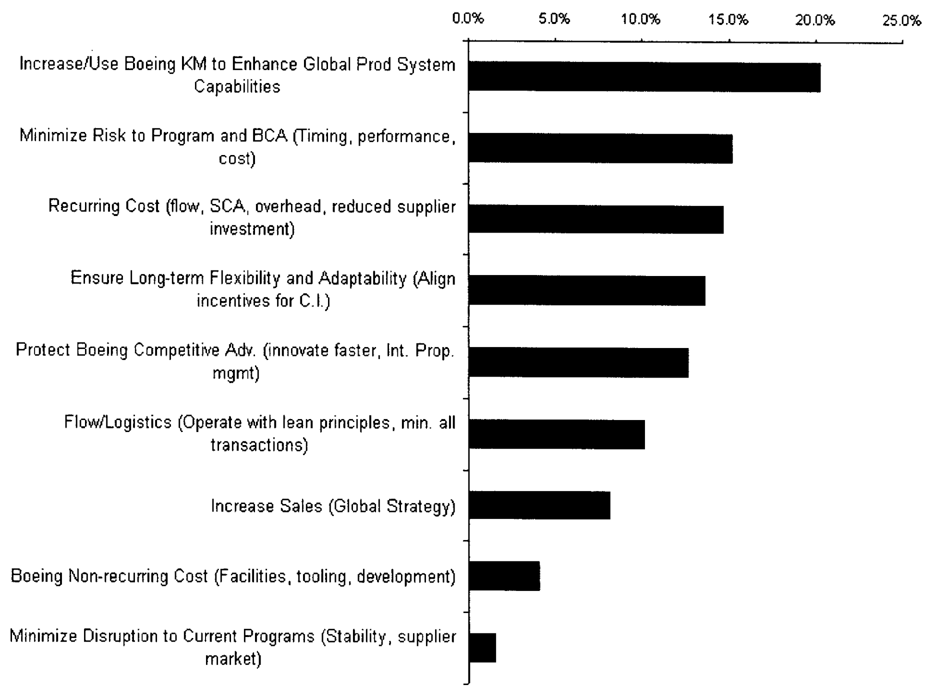
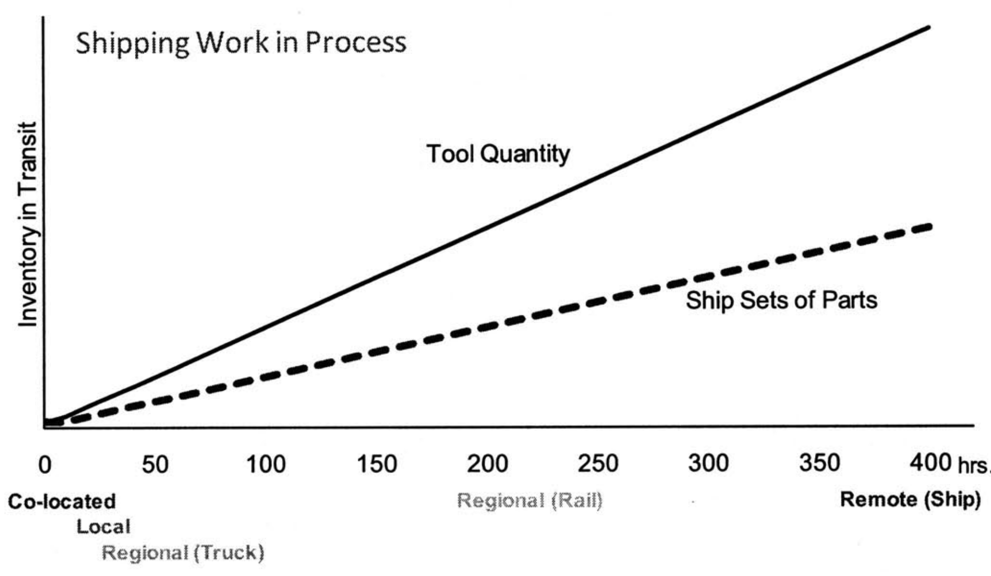


Figure 25: Relative Importance of Decision Criteria

In addition to the considerations outlined in previous chapters, other factors were also considered to understand the impact of different sourcing proposals. Boeing and the aerospace industry commonly use the learning curve. It is used to estimate the reduction in direct labor hours and cost based on cumulative increases in production. This theory proposes that the direct labor hours needed to build one unit of production will decrease by a fixed percentage with each doubling of cumulative production. An 80% curve means that there is a 20% improvement (100% - 80%) rate each time the cumulative production quantity doubles. In general, the aerospace learning curve is

85%. The learning curve for purchased parts can be up to 88%. This may be due to a less experienced workforce in the supply base and less capability and incentive for improvement when compared with the OEM. Cultural assumptions support the theory that Boeing will make more significant improvement in production than their supplier. This information suggests that there are greater incentives for continuous improvement, flexibility, and adaptability when components are produced internally. In contrast to high volume products (like automobiles) and military aircraft which use prototypes before launching production, commercial aircraft manufacturers optimize their products and processes during production (NASA, 2007). The harvest of continuous improvements is largely gathered after the first several units of production.

Transportation of airplane wings is a significant factor for both recurring cost and flow. Even though there will be shipping restrictions and requirements for special transport tools due to the size of the airplane wing, the airplane wing can be shipped to Puget Sound via ground, rail, ship, and air. The following chart characterizes a simplified view of system inventory based on shipping method and wing assembly location relative to final airplane assembly.



Assumptions:
- Does not include safety stock within inventory
- Extra tools for maintenance not included

Figure 26: Shipping Work in Process by Transportation Method

The three approaches were evaluated with a team of subject matter experts to provide directional input on the performance of each proposal by criterion.

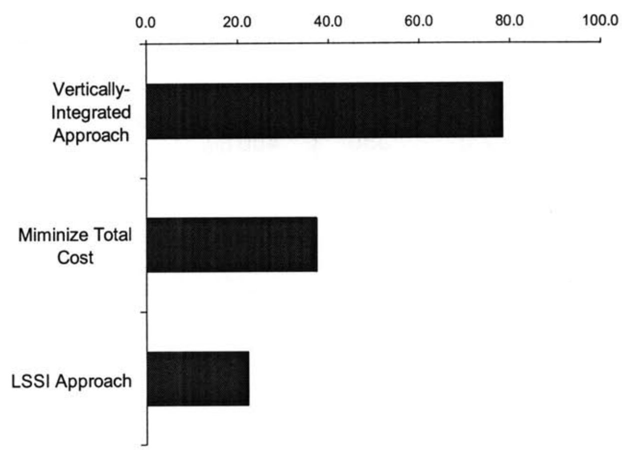
How well does each Scenario (column) MEET the Decision Criteria (row)? H = Significantly Meets Objective M = Somewhat Meets Objective L = Minimally Meets Objective	Importance	LSSI Approach	Vertically-Integrated Approach	Miminize Total Cost
Recurring Cost (flow, SCA, overhead, reduced supplier investment)	14.[illegible]%	L	M	H
Boeing Non-recurring Cost (Facilities, tooling, development)	4.0%	H	L	M
Minimize Disruption to Current Programs (Stability, supplier market)	1.[illegible]%	M	M	M
Increase/Use Boeing KM to Enhance Global Prod System Capabilities	20.2%	L	H	M
Protect Boeing Competitive Adv. (innovate faster, Int. Prop. mgmt)	12.[illegible]%	L	H	L
Increase Sales (Global Strategy)	8.1%	H	L	M
Minimize Risk to Program and BCA (Timing, performance, cost)	15.2%	L	H	M
Ensure Long-term Flexibility and Adaptability (Align incentives for C.I.)	13.[illegible]%	L	H	L
Flow/Logistics (Operate with lean principles, min. all transactions)	10.1%	L	H	M

Notional Data

Hypothetical data is provided as an example to visualize the process. Actual categories, weightings, and evaluations may differ.

Figure 27: Composite Wing Strategy Ratings by Criteria

Each strategy is rated (H, M, L) against all of the criteria. Those ratings correspond to a number which is then multiplied by the weighting to create a criterion score. The criterion scores are then summed for each approach. Each total score represents the grade of each distinct approach.



Hypothetical data is provided as an example to visualize the process. Actual categories and results may differ.

Figure 28: Composite Wing Strategy Scores

8.6 Recommendations

This study of the composite airplane wing scenario relies upon the stated assumptions and a proposed sourcing process that do not reflect the official views and operating processes of BCA. However, the results suggest that Boeing should pursue a more integrated wing design and production approach, matching the integral product architecture and the priority given to learning and knowledge. Some key elements are that wing integration should be co-located with final assembly and that Boeing should lead the integration process. Due to the rapid evolution of aerospace composites technology, Boeing should protect key intellectual property through a combination of formal agreements and internal work share.

Even though the fully-integrated scenario scored most highly, it is not recommended that everything be retained internally. There is a market of proven suppliers with capacity for the majority of systems and components. One way to evaluate which components can be more effectively integrated into the wing is to consider product modularity. The modified design structure matrix from Section 4.1 was used to identify areas with the greatest density of interaction. The DSM showed significant interaction between the main wing box and other components and systems. This reinforced that Boeing should maintain integration responsibilities for the wing. In addition, there is a larger degree of interaction between each category of system with the main wing box than the control surfaces. Combined with the reduced inventory safety stock and reduced inventory carrying costs, it makes sense for Boeing to lead the coordination and install those systems at the wing assembly co-located with final assembly.

8.7 Chapter Summary

The 737-replacement composite wing uses composite technology to enable its high performing, integral design. A cross-functional team developed a set of decision criteria and weightings to evaluate complex systems. Then, three general strategies were developed to satisfy the wing design and build sourcing. The evaluation results suggest that a vertically-integrated approach for both the design integration and wing assembly is more desirable than an outsourced or cost-minimization approach.

9 Conclusion and Next Steps

9.1 Conclusion

Effectively sourcing products is a challenge in structure, consistency, and execution. Due to the myriad of sourcing processes and work packages being evaluated, discipline is required to maintain process compliance with the appropriate type of sourcing decision process. Leadership strategy and vision must be embedded into the criteria and weightings to provide corporate alignment and process stability.

The discussion-based sourcing process being recommended for Boeing enables the company to take a more complete look at the short and long-term factors important in sourcing complex systems. This process standardizes key steps that increase transparency and documentation of the strategy, assumptions, thought process, and decision. The structured constructive dialogue brings out a balanced view which facilitates a more holistic approach to articulating the corporate strategies, priorities, and principles while making important vertical integration decisions. Strategic, technology, and financial factors like core competencies, product modularity, and cost are discussed in Chapters 4 and 5, and form the basis for evaluation criteria. Longer-term factors that build the foundation of future capabilities can now be standardized into the sourcing decision process. Decision criteria for new programs should be based on a set of factors similar to the criteria proposed in Chapter 7.

This work examined the level of vertical integration for a composite wing sourcing proposal. The composite airplane wing case study considered a wide range of strategic and economic factors to determine that a complex, integrated product with new technology should tend towards vertical integration. It is not enough to consider financial risk-sharing, global market access, and developing strong supplier partnerships. Those important factors must be balanced with creating the capabilities to improve Boeing's future product offering. At the time of this writing, it appears that Boeing is considering a wider range of factors in making future sourcing decisions. There are implications that cultivating internal capabilities and increasing control are considerations when looking at future derivatives and products. They have publicly suggested that they will rely less on outside suppliers and rein in the outsourcing on future derivatives of the 787 (Weber, 2009).

9.2 Opportunities for Improvement

The proposed process is able to provide directional advice and acknowledge areas of strength and risk. Oftentimes, use of a process that is too cumbersome or time-consuming may lead to poor process discipline or shortcuts. At the same time, this sourcing approach would benefit from increased detail and financial analysis in order to make important sourcing decisions.

9.3 Areas for Further Research

This sourcing process utilizes resources from many parts of the organization and considers a wide range of factors. There are multiple areas of research that would make this sourcing process more comprehensive. Some targeted areas are total system economics (total landed cost+) and the characterization of the current and projected state of internal knowledge, capabilities and industrial participation. A current weakness is that decisions are often made independent of each other. The characterization of the current and projected states will enable Boeing to coordinate multiple sourcing decisions. If a complex section of fuselage will be produced internally, then it will be less critical for other fuselage sections to be produced internally (from the knowledge and capabilities perspectives). One final area for additional research is to define a separate set of factors for existing work transfer.

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APPENDICES

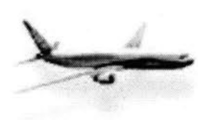
Appendix 1 – Current and Former Boeing Commercial Airplane Products

Current:

737NG

747

767



777

787 Dreamliner

Past:

707

717

727

757

DC-8

DC-9

DC-10

MD-11

MD-80

MD-90

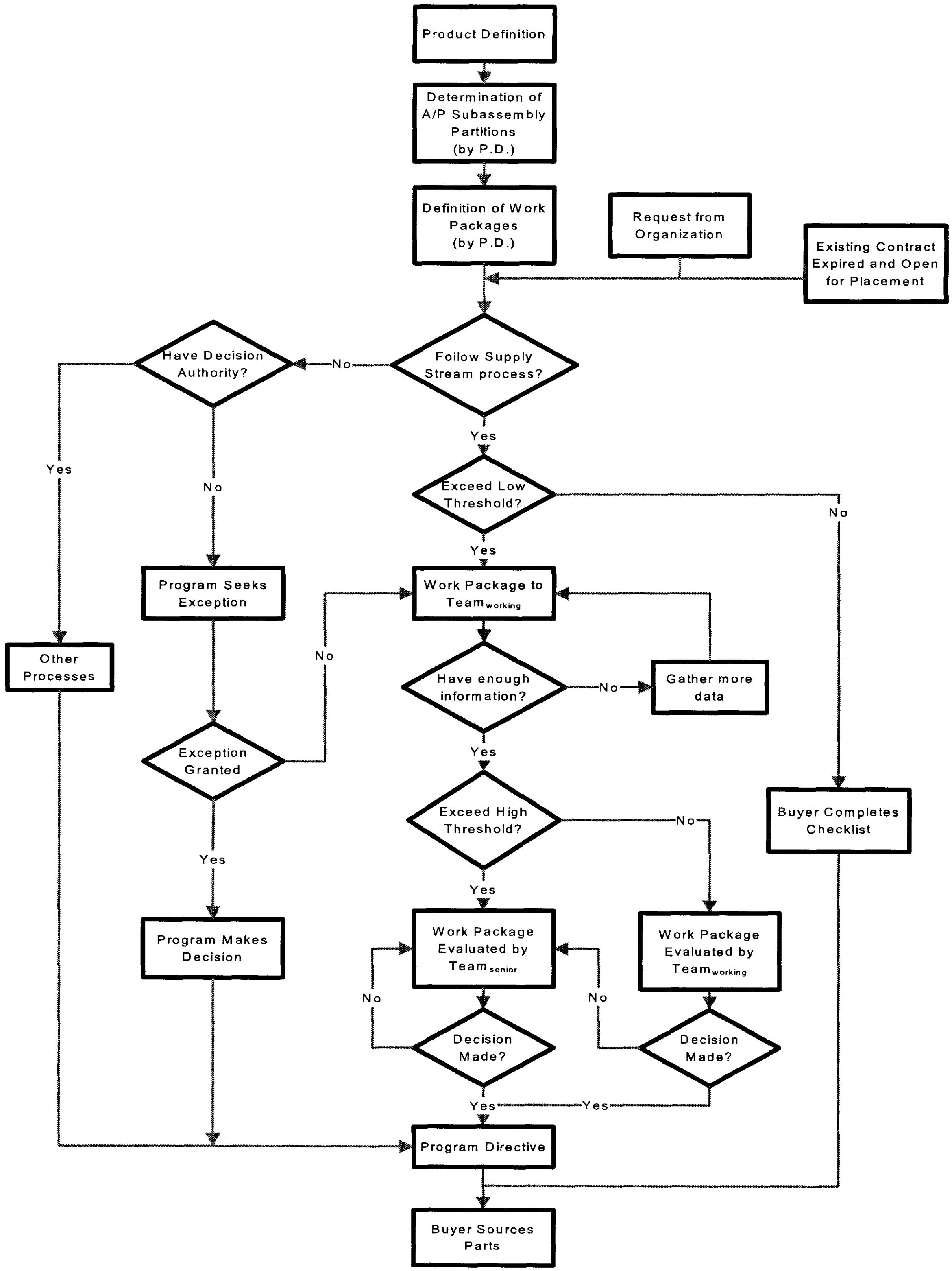
Source: www.boeing.com

Appendix 2 – BCA Fabrication Division Divestures

Plant Location	Description	Date Sold	Price	Purchased By	Number of Employees
St. Louis, MO	Manufactured metal and composites for military aircraft.	Jan. 2001	$61 million	GKN Aerospace (U.K.)	1200
Spokane, WA	Produced floor panels, air ducts and other components	Jan. 2003	$42 million	Triumph Group (Wayne, PA)	400
Corinth, TX	Produced wiring for military and commercial aircraft.	Jun. 2003	undisclosed	Labinal, division of Snecma Group (France)	900
Irving, TX	Produced avionics equipment.	Jun. 2004	undisclosed	BAE Systems (U.K.)	800
Wichita, KS and Tulsa, OK	Wichita assembled commercial-airplane fuselage and nose-and-cockpit sections; Tulsa produced smaller commercial-parts.	Jun. 2005	$1.2 billion	Onex (Canada)	9000
Arnprior, Ontario	Manufactured metal trays, shelves and other parts.	Aug. 2005	undisclosed	Consolidated Industries	370

Source: Dominic Gates, "Boeing Sells Fabrication Plant," The Seattle Times, August 4, 2005. (Gates, 2005)

Appendix 3 – Observed Boeing Sourcing Process for Large Decisions



Appendix 4 – Victor Mroczkowski Decision Support Matrix

Macro Category Breakdown

Strategic Analysis

When to...

In-source vs. Outsource

-5 ◄ Sourcing Spectrum ► +5

Technology Clockspeed	Fast	Slow
Product/Process Architecture	Integral	Modular
Supply Base Characteristics	None	Many
Enterprise Characteristics	Advantage	Disadvantage
Customer Value	High Margin	Low Margin
Exogenous Forces	Weak	Strong

Operational Analysis

When to...

In-source vs. Outsource

-5 ◄ Sourcing Spectrum ► +5

Demand Forecast Accuracy	Variable	Stable
Velocity	Fast	Slow
Quality	Essential	Non-essential
Delivery	Essential	Flexible
Capacity	Available (Internal)	Unavailable (Internal)

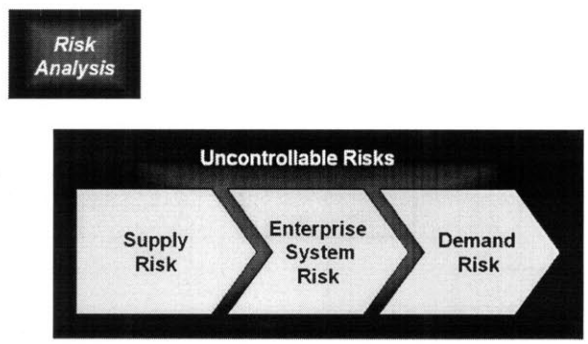
Financial Analysis

When to...

In-source vs. Outsource

-5 ◄ Sourcing Spectrum ► +5

Production Cost Per Unit Transportation / Logistics Cost Investment Cost Supplier Management Cost Tax Impact ΔLifecycle Cost	Based on relative cost advantages, either alternative may be advantageous



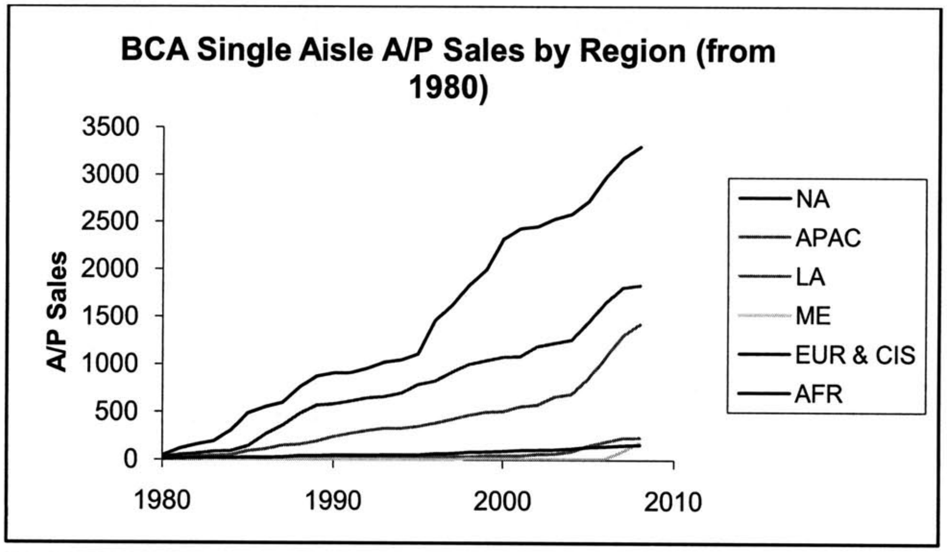
(Mroczkowski, 2008)

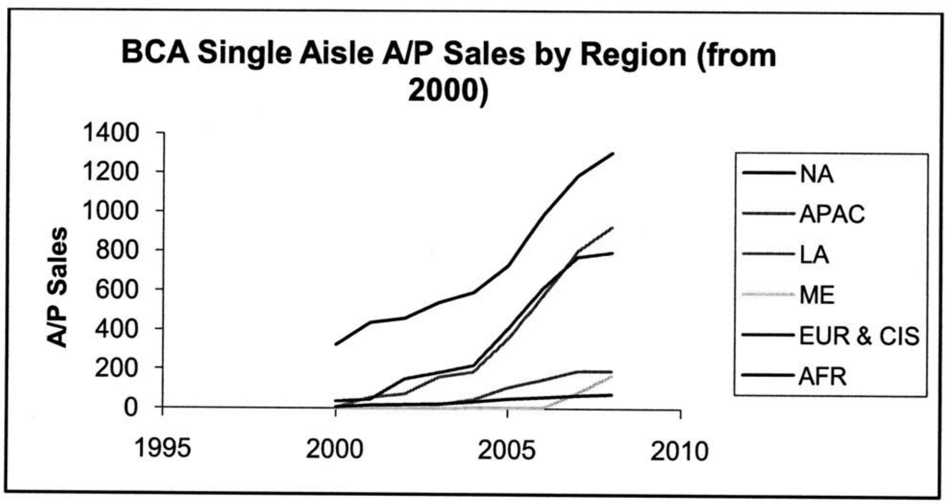
Appendix 5 – BCA 737 Sales through 2008

Cumulative Sales by Country from Calendar Year through 2008

Year	Australia	Brazil	China	Germany	India	Indonesia	Ireland	UAE	USA
2002	101	127	315	151	89	185	364	124	808
2000	116	127	357	160	89	185	367	124	1220
1990	135	134	466	264	109	221	444	124	2346
1980	231	139	488	384	116	224	611	124	3197

These charts depict sales starting in 1980 or 2000 (disregarding sales in previous years) to show the evolving global nature of single-aisle airplane sales. Even though sales have grown more global, the largest customer continues to be the United States.





NA – North America
APAC – Asia Pacific
LA – Latin America
ME – Middle East
EUR & CIS – Europe and Commonwealth of Independent States (former Soviet Union)
AFR – Africa

Appendix 6 – Glossary

7E7: The launch name for the 787 program. Some speculate the E symbolized environmental or efficiency

Autoclave: a large pressurized convection oven used to cure composite components

Backward integrating: moving into upstream activities which tend to produce a narrower set of more standardized outputs through more automates and capital-intensive equipment

Build to print: a type of outsourcing where the supplier builds parts to the customer's design

Clockspeed: a concept describing an industry's rate of product, process, and organizational change

Co-Bond: (787 Wing) to cure and bond uncured composite components with separate cured composite components in the same operation

Co-Cure: (787 fuselage) to cure and bond multiple uncured composite components in the same operation

Forward integrating: Moving into downstream activities which tend to produce a larger variety of more specialized outputs using more labor-intensive processes

IAM: International Association of Machinists, the union primarily composed of hourly skilled and non-skilled labor

Industrial Participation: government industry support regulations, where a government purchasing defense or aerospace equipment makes an effort to manage work-sharing arrangements to create or maintain industry capability

Insourcing: a situation where an outsourced services provider becomes a part of a client's operations, typically located in or near a client company's facility

Integral product architecture: a tightly coordinated group of subsystems with one to many mapping of complex and nonstandard interfaces

Modular product architecture: a flexible group of subsystems with one to one mapping of highly standardized interfaces

OEM: Original Equipment Manufacturer

Offshoring: a situation where typically developed economies send both knowledge-based and manufacturing work to other nations. This is typically driven by cost and access to human and material resources. Examples at Boeing are fabrication and the design and engineering of components. When the company owns the offshored operation (often for greater company control), it is called captive offshoring

Outsourcing: the hiring of an outside company to perform a task that would otherwise be performed internally by a firm

Pre-preg: a commonly-used type of composite material where the resin is pre-impregnated into the carbon fibers

Pre-stuffed: when components are first installed into major structures at the supplier before the completed assembly is shipped to Boeing

Secondary Bond: to bond separate cured composite components

SPEEA: Society of Professional Engineering Employees in Aerospace, the engineering union

Travelled work: incomplete work that should have been done at a previous supply tier that has been passed on to the next tier

Whitetail: a brand new plane with a white tail (vertical fin) with no airline logo because airlines are not able to accept the new plane

Work Offset: an agreement with a company or government to place work of a specified value in a location as an incentive for a particular sale. This can take the form of manufacturing, design, engineering, technology transfer, and training