USE OF INFORMATION TECHNOLOGIES IN THE PROCESS OF BUILDING THE BOEING *777*

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ABSTRACT

This article investigates how Boeing used global information technologies as a major factor in the process of designing and building the Boeing *777* aircraft. Information technology enabled paper-less design of the aircraft, reduced parts and rework, and ensured a reduction in the development cycle from 60 months to 48 months. The payoff to Boeing has been in improving customer relations, tying in suppliers more closely in the production process, aligning IS with corporate goals and objectives, and increasing use of design-build teams all through the organization. The success of Boeing in integrating information technologies to improve production lead-times and quality, without even creating a mock-up of the Boeing *777*, provides important lessons for other manufacturing companies. The lessons learned are that MIS needs to partner with design-build teams, include manufacturing workers in the teams, share knowledge, communicate with end-users, focus on customer needs, develop an appropriate IT architecture, and let end-users help develop content of the systems.

INTRODUCTION

Customers worldwide are becoming more demanding and expecting high product performance, quality, and overall value for their money (Condit, 1994). To succeed in this demanding environment, companies have adopted concurrent engineering principles to reduce the design cycle time, time-to-market, and costs (Salomone, 1995). Concurrent engineering is the simultaneous development of product and processes based on three fundamental elements of collaboration, processes, and information technology (Salomone, 1995). Collaboration means to work together or to cooperate with each other. Processes involve both the broader level of the full development cycle, as well as the detailed level of specific processes and specific design methodologies.

Information technology (IT) has become the foundation enabler that allows concurrent engineering to happen (Salomone, 1995). The IT could improve management of the engineering process through better control of data, of engineering activities, of engineering changes, and of product configurations. IT provides support for the activities of product teams and for concurrent engineering (Stark, 1992). The IT tools used in concurrent engineering include application programs, communications software, networks, frameworks, and database products. These tools help capture design intent with the exactness needed to rapidly transfer design ideas into manufacturing processes. In addition to the specific tools, generic tools such as e-mail, file transfer, video conferencing, etc., have provided significant help to the design process. These tools have become the primary enabler for the concurrent engineering process (Salomone, 1995). Even though these systems are computer-based, IT staff might have never worked with such systems, since traditionally they have developed systems to support finance and accounting systems. Therefore, learning about the successful implementation of engineering IT management systems is important to IT academicians and practitioners (Stark, 1992) given the importance of reducing manufacturing product life cycles in most industries.

The objective of this paper is to show how IT enabled the design and manufacture of the Boeing 777, a very large-scale project, and helped the company implement the philosophy of concurrent engineering, teamwork, and customer service. This objective was achieved based on literature review, interviews with Boeing executives, and experience of the authors in the aircraft manufacturing industry.

The next section discusses the major shifts to the organizational processes adopted by Boeing in the manufacture of the 777. The IT technologies used by Boeing in the design and manufacture of this aircraft are then discussed. These information systems are analyzed in order to identify the payoff for Boeing's customers, MIS staff, customers, and suppliers. This leads to identifying lessons for MIS managers and researchers.

MAJOR CHANGES ADOPTED BY BOEING IN THE MANUFACTURE OF 777

During 1990, the leaders in the commercial airplane industry were Boeing, Airbus Industrie, and McDonnell Douglas. In 1986, Airbus and McDonnell Douglas were building new planes - the A-330/340 and MD-11/12 to carry between 300 and 400 passengers on trunk routes. Airbus and McDonnell-Douglas had modified their internal systems and were effectively producing new products in a shorter developmental cycle than Boeing. Both were using new techniques and procedures, leveraged with the use of telecommunications in an attempt to erode Boeing's dominant position in the marketplace. These planes were designed for airlines that wanted to fill the gap between the 200 passengers that a Boeing *767* could carry and 425 passengers that a *747* could carry. In 1992, United Airlines placed a multibillion-dollar order with Airbus instead of Boeing, its historical supplier. Boeing was forced to design the Boeing *777* to fill the gap in demand and to cover the market for aircraft carrying between 300 to 400 passengers.

Since Boeing was already late in entering the 300-400 passenger aircraft market, it was pressured to decrease the Boeing 777 developmental cycle from the traditional 60 months down to 48 months. Condit, then Executive Vice President and General Manager of the Boeing 777 division, envisioned that success was not always to the swift, but to those who used technology in the most efficient way to deliver the right product, at the right time, and at the right price (Condit, 1994). He wanted to improve the process by which the company had traditionally designed and built aircraft. He states:

> To improve this process, we decided to use two methods, or communication tools, to help design the plane. First, we used design-build teams that included people from engineering design, finance, operations, manufacturing, customer support, suppliers – as well as customers. The design-build teams evaluated the design from various perspectives before the designs are released to manufacturing.
>
> Second, engineers from these teams are using powerful computers to create the aircraft design. Our shift to a "paperless" airplane required a massive investment in computing technology – but is an investment in our future.
>
> Boeing's success in the marketplace depends upon designing and building products that provide the best solution to our customers' changing needs. The test for all our R&D efforts to create new or better products is their effectiveness in adding value for the customer.

The changes in management style in the design, build, development, and testing of the 777 could be categorized into five aspects according to Condit (1994):

(a) *The organization changed from separation of functions to strong team orientation*: Boeing's organization used to be a barrier-oriented organization (BOO) composed of functional divisions such as engineering, finance, manufacturing, etc. (Condit, 1994). This was replaced with a strong team orientation with the use of cross-functional teams. It led to cost-based design at the outset rather than those things being imposed on the design in the classic linear fashion – where the design went from engineering to manufacturing and then, finally, to the customer who said, "You didn't get it right." Larry Olson, Director of IS at the Boeing's *777* project, and his staff transformed themselves from second-class citizens to peers of their technical colleagues (Garner, 1996). One thousand men and women from IS were tagged to work on the design-build teams for the *777* project.

(b) *The organization shifted from strong orientation to the individual to knowledge-sharing*: In the "BOO" environment, knowledge was power and people used to leverage information in order to get promoted. This focus changed to sharing knowledge among teams in the *777* project. That meant that each of the 238 design-build teams responsible for designing and manufacturing such things as doors, wiring, hydraulics, and payload included at least one person from the IS staff. They provided the computing tools so that the team of technical people could solve complex problems and communicate with the different technical disciplines to solve problems (Garner, 1996).

(c) *The company changed its focus from internal competition to external competition*: Before the *777* project, competition in Boeing was function versus function, department versus department, product line versus product line, and individual versus individual (Condit, 1994). This focus changed in the *777* project to asking questions such as – what is the best process in the world? Who does this best? Who handles accounts receivables better than anybody else and how can Boeing make its systems look like that? They started to compete by asking, "Who's best, and how can we be better than that?" (Condit, 1994). For the first time, engineers depended on the IS staff for helping to get their designs into the computer, sharing their design with everyone else, and working through the process issues. Thus the IS group was able to deliver, and that's how the group became a stronger, better organization (Garner, 1996).

(d) *The fundamental thrust shifted from product-orientation and technology-push to process orientation*: Before the building of Boeing *777*, people at Boeing Corporation had a lot of knowledge about the product and its characteristics and a lot of research was done on new technology. The *777* project shifted this fundamental thrust to process orientation, where things like cycle-time, time-to-market, and response to customer's desires became the driving forces (Condit, 1994). The IS department changed its focus on computing as the end-all to focus on customer requirements (Garner, 1996).

(e) *The organization's disconnection with the customer was changed to be customer-focused*: The *777* team changed its focus to be customer-focused and strived to understand the customers better than how even the customers understood themselves (Condit, 1994). The customers were brought into the design-build teams and this led to internal people stopping acting like they were surrogates for the customer. IS focused anew on working closely with the internal customers by closing the loop and making sure that they had done what the customers required instead of providing a solution and brushing off the hands. (Garner, 1996). This led to development of reliable information systems that Boeing engineers were able to trust and take for granted (Alter, 1996).

The above changes in management styles for Boeing were enabled by the adoption of many new IT tools by Boeing, its customers, and its suppliers.

IT USED BY THE BOEING *777* TEAM IN THE PROCESS AND PRODUCT

Information technology tools and techniques played a critical role in the design and development of the *777*. These could be divided into three categories: (1) those that were used during the process of designing and developing the aircraft, (2) those that were integrated into the final product, and (3) those that were used for testing the aircraft and training the workers. An overview of the IT used in the three categories is provided next.

(1) IT Used in the Process of Design and Developing the *777*

A decision was taken to proceed with massive changes in computer and telecommunications systems to support a revolutionary method of design, production, coordination, and control for the *777* project with a budgeted investment of $5 billion. Using digital product definition, designers created parts and systems as three-dimensional solid images instead of the traditional two-dimensional drawings. The IT tools used in digital product definition and digital pre-assembly reduced design errors and improved the manufacturing processes. Some of the major IT tools used by Boeing were integration of computer and telecommunications systems to support processes, integration of CAD systems, improvements to the parts tracking system, use of robotics, and improvements in materials handling technology. Each of these is discussed next.

(a) Integration of computer and telecommunications systems to Support Processes: Up to the Boeing *777* project, Boeing depended on processes that were developed in the 1940s to track aircraft development and production. The earlier process required 800 different computer systems to manage it, with most of the computers unable to communicate with each other. These systems tracked the several million parts that went into each aircraft produced, rather than tracking the development of the aircraft itself. They were somewhat efficient when tracking the production of over 10,000 identical bombers in World War II, but created major problems in producing airliners, as each airline wanted its aircraft configured differently based on individual airline needs. The earlier process was based on a design-mockup-rework-prototype-test-revise-produce-test-revise-produce-test cycle and was inherently inefficient. It had driven up costs, lengthened production time and created a sprawling bureaucracy. For example, it took two and one half years to train draftsmen to understand the systems. Even after being trained on the system, they committed at least one error on one third of their drawings (Taylor, 1995). This resulted in little integration of suppliers, vendors and customers.

The development of the Boeing *777* required that the IS division quickly build a global network using submarine fiber-optic cable to support integration of the process between suppliers, vendors, internal, and external customers. This allowed foreign and U.S. sub-contractors to share data with Boeing. It also required supporting 2,400 computer-aided design and manufacturing workstations on eight IBM mainframes reliably (Alter, 1996). The bulk of the international Computer Aided Design (CAD) data was transmitted between Boeing headquarters in Seattle and a central data center in Nagoya, Japan. From Nagoya, the CAD data was sent over T1 lines to manufacturing plants operated by Kwawasaki, Fuji, and Mitsubishi. Over 5,000 files, consisting of nearly 12 gigabytes of CAD data, were transmitted between these points per week.

In all, approximately one and a half billion bytes of data were sent over the project's underwater T1 connection. A satellite T1 connection provided a back-up link (Jordahl, 1995). Other sites connected to the T1 network included engine manufacturers Pratt and Whitney as well as General Electric in the U.S. and Rolls Royce in England. The Boeing plant in Wichita, KS, and a small bracket manufacturing facility located in Winnipeg, Canada also shared CAD information over the system. The network streamlined configuration control by allowing lead engineers in Seattle to transmit component designs to their counterparts in Japan, who made necessary modifications using a separate workspace file. The design was then sent back to Seattle for approval. Two new systems, the Computer graphics Aided Three-Dimensional Interactive Application (CATIA) and the Electronic Preassembly In the Computer (EPIC), were introduced in order to integrate the processes.

(b) Integration of CAD systems and Widespread Availability of CATIA and EPIC: Boeing integrated its Computer Aided Design (CAD) systems using CATIA and EPIC so that the *777* design teams could access them from anywhere in the world and create virtual mock-ups instead of physical mock-ups. Boeing distributed 2,200 computer terminals to the overall *777* Design Team. The terminals were connected to, and by, one of the largest grouping of IBM mainframe computers in the world. This provided key participants in the design process, ranging from airframe manufacturers in Japan, to engine manufacturers in the U.K. and U.S., immediate access to data. The system also allowed all involved in the process to be aware of changes as they were made and confirmed. These teams were linked electronically in order that actions taken by a team that impacted others could be broadcast quickly.

CATIA was used to design specific components and was based on a Dassault/IBM system that was introduced to Boeing in 1986. This system allowed engineers to design components in three dimensions and ensured that they would properly fit and operate before they were physically produced. Use of the virtual mock-ups significantly reduced effort in systems integration for aircraft manufacture as compared to the use of physical mock-ups. Boeing Chief Project Engineer for digital product design, Dick Johnson, stated, "With the physical mock-ups we had three classes: class 1, class 2, and class 3. The engineer had three opportunities at three levels of detail to check his parts, and nothing in between. With CATIA, he can do it day in and day out over the whole development of the airplane, and so it's a tremendous advantage."

EPIC allowed the different components of the aircraft to be designed and integrated into a computer simulation of the whole plane. This was a system designed by Boeing for initial implementation in the *777* project. It allowed engineers to integrate all the systems on the aircraft to ensure that there were no interferences, and that all components interacted appropriately. Engineers using this system could view individual parts from varying perspectives, as well as operate the component as it was projected to be built. These components were then linked in a virtual mock-up for systems integration. The introduction of the EPIC system made possible a direct link between the computer description of the design of a component and the instructions that a machine tool would need to make it. This eliminated the earlier habit of "throwing the design over the wall" and letting production worry about creating the equipment.

The apparent freedom to change parts until they became final could have led to absolute confusion as engineers constantly "tinkered" with their systems. Boeing countered this by imposing periodic design "freezes" in place, where engineers would be forced to resolve conflicts their parts or systems created with all other systems. Resolving conflicts was critical in the design of the rudder, fuselage doors, the fuselage, and engines, since all these components were produced by subcontractors, mainly outside the continental United States. For example, the rudder for the *777* was produced by ASTA in Australia, using Boeing carbon-fiber technology in a German-built autoclave. Changes in the rudder design had to be fed to ASTA in Melbourne to meet production deadlines in the United States. Analysis of the rudder design revealed that there would be some aerodynamic "flutter" requiring a change in the design of the component. ASTA's representative to the rudder design-build teams provided constant input to her parent company, allowing them to strive to meet production deadlines.

Although CATIA was expensive to introduce and initially cumbersome to use, the system helped Boeing eliminate 65 percent of change errors and rework, 15 percent better than the target set. CATIA also saved Boeing from having to make expensive engineering mock-ups of the *777* before it built the real aircraft (Guy, 1995). Digital mock-ups provided engineers with the physical reassurance of a design before they committed the design to production.

(c) Improving the Parts Tracking System: Before 1990, Boeing had a process called "Effectivity" that manually tracked which parts went into which airplane. This required that customer identification numbers be placed on drawings of every part of the specified airplane. The numbers also had to be manually added every time the specifications or requirements changed depending on the configuration of the ordered airplane. Additionally, lists of parts produced by the engineering department for a given airplane were configured differently from lists put together by manufacturing, customer service, or other Boeing operations. This caused the parts lists to be broken down, converted and recomputed as many as thirteen times during the construction of a single airplane (Taylor, 1995). The head of the commercial airplane division, Ron Woodard, stated, "Effectivity just doesn't make sense. The tabbing and retabbing of drawings accounts for a large percentage of engineering hours, adds absolutely no value to our products, and results in tremendous costs." He also noted that McDonnell Douglas had eliminated this system and that Airbus Industrie had never used it (Taylor, 1995).

Instead of treating parts as unique, Boeing *777* teams grouped them into three categories, based on their frequency of use. This included the use of the same parts in different planes reducing the variety of parts, which reduced costs by 25 percent, reduced defects by 50 percent, and shrank the order to delivery time by 40 percent. For example, fuselage doors and door hinges on previous Boeing aircraft were individually designed for a specific position on an aircraft. Even on a single aircraft there was little commonality of parts between doors, thus complicating design and leading to manufacturing problems. Boeing decided to try to make as many parts common as possible for the *777*. As a result of using the new IT tools, door mechanisms and door hinges were 98 percent common for all the doors on the *777* aircraft.

The tracking system ensured that all parts were delivered when and where they were needed. The system tracked parts, including delivery of engines from the U.K. or the eastern U.S. to delivery of wing components from other Boeing manufacturing facilities in the Seattle area. Boeing's system tracked key items including state road restrictions, road construction that impacted movement of materiel for the next ten years, and the impact of weather patterns on movement. This required the transportation manager for the *777* project to track origin and size of every component of the airplane, and preferred or required delivery modes (air, sea, rail, and truck). Inventory management ensured that parts were delivered, as they were needed, rather than storing components for long periods of time. Global telecommunications ensured that this system worked effectively in linking more than 3,000 domestic suppliers and 300 foreign sources located in 23 countries. Even with the use of several foreign manufacturers, the use of the new parts tracking systems created a collaborative environment among the designers, manufacturers, and suppliers of parts.

(d) Use of Robotics in Manufacturing Process: Actual assembly of the Boeing *777* utilized telecommunications systems to coordinate manufacturing between suppliers and Boeing. Robotic tools were constructed that could receive CATIA design data and respond to instructions to abrade surfaces by thousandths of an inch. Robotic tools for assembly included the Automated Spar Assembly Tool (ASAT) tool that robotically assembled wing panels that were over 90 feet long. Tools that assembled the aircraft also were designed and built to keep from slowing the production of the aircraft. Boeing considered formulation of tools and assembly practices as critical to the production of this aircraft.

Components that had been designed in the computer had their specifications transmitted to various Boeing and subcontractor manufacturing facilities. Specifications were exact to the point of rivet hole and attachment placement. Criteria were so strict that when the wing was assembled for the first time, the wing expanded by 2 thousandths of an inch due to molecule displacement, causing specifications for the wing skin to be changed before it was produced. This eliminated the requirement to place costly shims in place to mate the wing spars and the wing skin.

(e) Improvements in Materials Handling Technology: Manufacturing times and cycle times for the *777* were reduced by taking advantage of new material handling technology. Traditional facilities relied almost exclusively on overhead cranes to handle work-in-process. Inventory levels and materials handling used to be high since the work-in-process flow in the facility was cumbersome. A Just-in-Time plant designed in Tacoma to build the tail sections of the Boeing *777* minimized work-in-process and cut cycle times by 65 percent. Automatic guided vehicles (AGV) were teamed with overhead handling equipment to meet the needs of workers. Using computer terminals at their workstations, workers requested delivery of parts by AGVs. All routing decisions were under computer control. The use of AVGs and overhead storage system reduced floor space requirements and saved $12 million in building construction costs. In addition, it significantly reduced the possibility of damage to parts due to transit and minimized shop disruption during moves (Forger, 1994).

(f) Summary of IT Changes Made in the Process of Design and Manufacturing of the Boeing *777*: As a result of the innovative use of processes that were dependent on telecommunications tools, the *777* program reduced change, error and rework by 65 percent. Parts and systems fit together better than anticipated and at the highest levels of quality. The first *777* produced were 0.023 of an inch away from perfect alignment, while most aircraft only line up to within 0.5 of an inch. Charles Kyle, a Boeing project engineer stated, "Digital preassembly helped us significantly improve our engineering and manufacturing processes, and the overall quality of our product. We've been able to use this technology to lower our costs and decrease the time it traditionally would have taken to introduce this airplane into the marketplace. The *777* is a marvelous achievement of teamwork and technology" (Boeing *777*, 1995). Not only was IT used to improve the process, it also formed an integral part of the product itself.

(2) IT Systems Used in the Product: The Boeing *777*

In all, the Boeing *777* had more than 2.6 million lines of code incorporated in the avionics and cabin-entertainment system, compared to 400,000 in the 747-400. The important IT tool was the overall Aircraft Information Management System (AIMS) which had over 2 million lines of computer code. AIMS catered to three sets of customers: flight crews, maintenance people, and passengers.

AIMS was designed so that the flight crew's load would be easier when they fly the airplane. The system consisted of dual cabinets that contained all the central processing and input/output hardware needed to handle flight management, flat-panel cockpit displays, and central maintenance of the plane. Even if one of the two AIM cabinets was not functioning, the aircraft could still be flown. The cabinets were built on advances in application-specific integrated circuits (ASICs), so that more channel functions could be integrated in a single processor channel (Guy, 1995). This was the first aircraft to use optical-fiber cables to connect AIMS, maintenance access terminals, and side displays in the cockpit. The AIMS interfaced with the Global Positioning Satellite System (GPS) to allow accurate navigation of the aircraft over long distances. The AIMS system was built so that it would not provide misleading information to the maintenance people and point out the parts that had failed. The equipment was built to be fault-tolerant so that when a system failed, another took over.

About 40 percent of the computing power of AIMS was taken up with the extensive passenger information system (Sabagh, 1996). Every passenger seat was equipped with a telephone (including fax capability), a video screen offering up to twenty different channels, interactive computer games, and "in the sky" shopping facilities by credit card. Other systems were designed to take care of passenger's comfort such as the air temperature, water availability, food service, etc. These systems alone required 1,700 computers per aircraft as compared to 180 for the rest of the avionics. All electronic systems were built to be compatible with international requirements and allowed the aircraft to effectively operate worldwide.

Another IT tool used in Boeing *777* was the introduction of the fly-by-wire flight control systems. This system made it possible to use lighter wing and tail structures by obviating the need for complex and heavy mechanical cables, pulleys, and brackets. The pilot's commands (through the control yoke) went to three control computers that formed the heart of the system. The system gave the pilot the important seat-of-the-pants feedback he/she would get from direct-link mechanical controls (Guy, 1995).

(3) Use of IT in Testing and Training

Boeing created a plan to test the aircraft so thoroughly before entry into service that the U.S. Federal Aviation Administration and European Joint Aviation Authorities cleared the *777* for extended-range twin operations (ETOPS). This extended service allowed airlines to fly routes that involved long flights across water, three hours (180 minutes) away from the nearest airport. To achieve these plans, Boeing devised a $370 million Integrated Aircraft Systems Laboratory to allow full "flights" to be enacted on the ground. Up to 57 major aircraft systems, 3500 line replaceable units, and 20,000 parts were tested and integrated with other parts. The IT tools permitted the systems to test avionics with real-time simulations of the aircraft in flight. Another lab handled the validation of the fly-by-wire flight control system. The third lab was a *777*-cockpit simulator.

The test program was designed to facilitate certification for 180-minute ETOPS before its first revenue producing flight. The success of the test program allowed immediate use of the aircraft on most intercontinental and domestic routes. While the entire aircraft system was tested, the Aircraft Information Management System (AIMS) and the engine systems were tested more rigorously. The test program was designed so that the *777* would meet requirements that most airliners accomplished only after their first two to three years in service.

The aircraft had to be individually certified for operation with each of its engine combinations. For certification, an ambitious test program was developed that required 1,000 cycles (take-off and landings) per test aircraft. A significant amount of these flights had to be conducted in all weather conditions and over long distances. Computer models were used to determine the best possible techniques for testing the aircraft, from cold weather operations in Montana to hot weather operations in Phoenix and Edwards Air Force Base in the Mojave desert. Also incorporated in the test program were requirements generated by airlines that would be operating the aircraft. An example of this was a test of the carbon-fiber brakes under a significantly higher load, based on worst-case requirements by British Airways. After passing a series of rigorous tests during the year following the first test flight on June 12, 1994, the FAA approved on May 30, 1995, the 180-minute ETOPS for the Boeing *777*. The first commercial flight from London to Washington D.C. on June 7, 1995 was successful and trouble-free.

Boeing created a new $109 million training center at Seattle to provide comprehensive, world-class support services for its airliner products (Proctor, 1996). In the past, the course for maintenance technicians was tedious – up to 95 percent instructor-led sessions – lasting up to 75 days for a full program. With service entry of 747-400 in 1989, computer-based training stations were added, dropping the duration of the full course to 64 days. The duration of training for the *777* was further cut to 47 days by teaching students how to identify and troubleshoot problems. The students spent about 50 percent of their time on hands-on training. Exercises were structured to match actual work scenarios, such as problems students typically would encounter every day. The instructors were supported with overhead projectors allowing graphic display, sound clips, and other multi-media tools that could directly connect to the *777*'s printed manuals. Teaching materials and software were updated every 60 days, mirroring changes to the *777*'s Systems Description Manual. The training center's built-in fiber optic network quickly moved data so students did not wait between instructional segments. Boeing is also using RealVideo to provide its employees access to new, live, and on-demand tools for training and corporate communication. Overall, the reduction in the course duration led to lower costs associated with training and lodging students (Proctor, 1996).

SUMMARY OF IT USED BY BOEING *777* TEAMS IN THE PROCESS, PRODUCT, TESTING AND TRAINING

Table 1 summarizes the information technologies used during the process of designing, building, and testing the aircraft and the IT deployed in the aircraft itself. The advantages provided by the IT are also shown along with a listing of the IT technologies that enabled these changes to happen.

Payoff for Boeing's Managers, Employees, Suppliers, Customers, and IT Division

The changes enumerated in Table 1 had significant payoff for Boeing and its IT division. Boeing's success could be attributed to the reduction in costs and production time. According to Bob Dryden, Boeing Commercial Airplane Group Executive Vice President, "We must continue to reduce our costs because it will be key to selling airliners at a price airlines can" afford (Boeing Executive, 1995). The *777* was rolled out and made its first test flight on time on the12th of June 1994, 45 months after the order was placed by United Airlines on October 16, 1990. Extensive flight-testing took place during the next year and United took delivery of three *777*s by June 1995. Each plane costs between 128 to 144 million dollars. Boeing's deployment of IT tools have created payoffs for the management team, employees, development of new aircraft, suppliers, customers, and the IT division. These are described next.

Category	Enabling Information Technologies	Advantages to the Company	
		Before the *777*	After the *777*
Process of manufacturing aircraft	• Integration of computers and telecommunications systems • Widespread availability of CATIA and EPIC • Improved parts tracking system • Use of robotics • Improved materials handling technology	• 800 different computer systems • Throw design over the wall • Many change orders and rework • Parts unique for each aircraft • Costly shims needed to be installed • High work-in-process	• Created a globally Interconnected network • Virtual mock-up instead of physical mock-up • Eliminated 65% of change errors and rework • Common parts for aircraft • Reduction of shims • Reduction in work-in-process
Aircraft itself	• Create Aircraft Information Management System • Create fly-by-wire flight control system	• Analog technology • 400,000 lines of code in 747-400 • Maintenance at global locations difficult • Limited passenger information systems • Needed complex and heavy equipment	• Digital technology • 2.6 million lines of code • Maintenance made easier by building fault-tolerant systems • Extensive passenger information systems • Provided seat-of-the-pants feedback
Testing and Certification of Aircraft, Training of employees	• Created test labs for ETOPS certification • Computer models to predict weather conditions • Created computer-based-training modules	• Twin engine aircraft not allowed for intercontinental flights • Actual flight needed to test aircraft • Required 75 days training for mechanics	• Twin-engine aircraft was tested and certified in record time. • Many difficult weather conditions were simulated in the lab • Reduced training time to 47 days

Table 1: Information Technologies Used by Boeing During the Life Cycle

(1) Payoff to Management Team

Boeing's *777* division received the Computerworld Smithsonian Award for the manufacturing category during 1995 (Taninecz, 1995). Phil Condit was named Chief Executive Officer of Boeing in March 1996, based in part on his performance in the Boeing *777* project (Condit, 1996). The initial *777*-200, which was first delivered in May 1995, had a range of up to 5,680 miles. By November 1997, 335 Boeing *777*s had been delivered to customers. The increased-gross-weight, longer-range *777*, called the *777*-200IGW, were first delivered in February 1997, priced between $134 to $153 million. This model is capable of flying the same number of passengers up to 8,320 miles. Boeing also is developing a stretched version of the *777*, providing three-class seating for 368 to 394 passengers on routes up to 6,200 miles. First delivery of this high-capacity *777*-300 is scheduled for spring 1998 to Cathay Pacific Airways of Hong Kong at a price of $149 to $171 million. In this way, the market-driven approach that led to the *777*-200's launch in 1990 continued to shape the *777* family with the stretched -300. By investing in IT technologies, Boeing has created a formidable barrier for other aircraft manufacturers to enter this market. The recent acquisition of McDonnell Douglas further minimizes the number of competitors to Boeing to one, Airbus Industrie.

(2) Payoff to Employees

Boeing and Dassault have introduced four revisions of the CATIA software since 1990 and are continuing to make the system easier to learn and use. The Design-Built-Teams for the new stretched version of the *777* is composed of both supervisory and non-supervisory staff compared to only supervisory staff for building the *777*. A lesson the company learned was the tool-makers did not participate in the design-build teams leading to expensive changes. Therefore, the company has allocated some $100 million plus to activities led by non-managers in the manufacturing shops. They can decide whether to hire a lot of inexpensive people or to trade numbers for resources. The new organization and greater experience with software have allowed Boeing to set a 32-month schedule for development of the Boeing *777*-300, between 10 and 14 months less than such a program would have taken in the past (Sweetman, 1996).

(3) Payoff toward Development of 737s

Even though Boeing might not receive a reasonable rate of return for the capital spent on the building the *777*, a major payoff is in reusing the lessons learned during the building of the *777* to production of the 737s – its longest running and most successful transport program (Brown, et al., 1997). Boeing had delivered 7,360 of the 737 aircraft by November 1997 to airlines around the world. The core of the wing, the shape of the chord for the 737, had been changed to apply the advanced aerodynamics of the *777* wing for improved performance at cruise speeds.

Another feature of the 737-600/-700/-800 models is maintaining crew commonality with the flight deck of over 1,800 current generation 737s that have already been ordered. For example, installing the new Flight Deck Common Display System increased crew commonality by incorporating programmable liquid-crystal displays. One of the most interesting features was a software program that allowed the LCDs to display formats of previous 737 types, by simply using a computer disk (Woolsey, 1996). Such consistent flight deck design philosophy reduced training time between airplane families and simplified mixed-fleet flying in related markets.

Boeing's consistent flight deck design allowed pilots to transition to the next larger family in 11 to 15 days across their entire product line, and even to transition from their newest 737s to the *777* in just 15 days. In the airline industry, pilots typically move up a career ladder from small to medium to large airplanes. With less transition training time on Boeing airplanes, pilots would spend more time flying in revenue service, thus increasing total crew productivity for the airlines. Even though Boeing recognized that the markets served by the different kinds of aircraft are different, IT tools and technologies were effective in reducing unnecessary inventory and redesign of aircraft. This led to a reduction of threats from substitute products and services.

(4) Payoff for Suppliers

The suppliers of parts have been exposed to new methods of electronically conducting business that led to reduction in the number of parts to be manufactured, an increase in quantity for each part ordered, and the ability to look at design diagrams rapidly, and provide feedback to design engineers. In addition, the suppliers have been able to mesh their parts design with the aircraft specifications and check whether their product will meet the needs by using the CATIA system. This resulted in less wasted design, development, and implementation effort for the suppliers. Also, since the suppliers worked with Boeing with the new systems in the manufacture of the *777*, possible competition has been reduced since new suppliers have to learn the CATIA system. Boeing used telecommunications to allow for rich communications in an integrated problem solving environment (Wheelwright, 1994). Boeing has also been very careful about where it buys components. In countries that are large potential customers, Boeing seeks to develop suppliers (Porter, 1986) thereby earning loyalty from its customers.

(5) Payoff for Customers

Boeing's effort to revolutionize the way it designed and produced airplanes is paying off for the customer. The prices for the largest 737-800 are $48 million to $54 million compared to the current 737-400 of $42-48 million. With a two-class interior, the 737-400 can fly up to 2,400 miles (3,870 km) with 146 passengers aboard. Largest of the 737s now in production, the 737-800 can carry 162 first- and coach-class passengers more than 3,340 miles (5,370 km).

The buyers of the aircraft have been able to participate in the design and building of the aircraft and have been able to reduce unnecessary items and improve needed items. Their participation in creating requirements, such as the Flight Deck Common System and AIMS, have led to improvements in the productivity of their flight crew and maintenance people. Concurrently, Boeing has created a set of customers who will be reluctant to take their purchases to competitive aircraft manufacturers.

(6) Payoff to the IT Division

Boeing's IT division has created a major Intranet that has become the standard communication tool throughout the entire company. It has wired many of its employee workstations to the Web. Oversight of Web technologies and policy runs on an estimated $1 million budget. The IT staff are finding the balance between putting the tool in the hands of the process business units and providing guidance. The content has been delegated to the divisions because that is where the accountability rests. For example, the Wing Responsibility Center that builds wings, tails, and rudders for the aircraft used the Intranet as a major IT tool in bringing people together instead of relocating them. Dozens of sites made content available to employees, including the Web version of its spares ordering and inventory system, employee news services, a library, and human-resources information (Frook, 1997).

Another change is that the IT employees are part of the Design-Build teams all across the company. This has led to barriers being taken down and people honestly speaking with each other at any level of the hierarchy (Garner, 1996). This change in focus has changed IT from a support role in Boeing to become a major enabler in competing with other aircraft manufacturers.

LESSONS TO BE LEARNED FROM THE BOEING EXPERIENCE FOR IS PROFESSIONALS

Boeing has concentrated most of its design and manufacturing activities and coordinated the dispersed activities extensively using the IT network and technologies (Porter, 1986). The experience of Boeing in adopting IT as an enabling technology has valuable lessons for manufacturing companies and IT researchers.

Boeing has identified its core competencies to be detailed customer knowledge and focus, large-scale system integration, and lean, efficient design and production systems. Use of IT by Boeing has reduced costs, increased coordination between internal departments, customers and outside vendors, and has resulted in the maintenance of its competitive market share as the air transport industry rebounds. Boeing treated airplane design as a whole, including, "not only airplane hardware, but also the plans to build parts and tools for assembly. With today's improved practices, we don't consider the design complete until we finish all these aspects," according to Lars Andersen, chief project engineer for *777* Airplane Design. Andersen goes on to say that, "Customer participation design/build teams, open communication and digital design were all factors in reaching the *777* milestones on time" (Next Member, 1995).

Boeing's example in incorporating IT as enabler in both process and product points the way for other manufacturers to improve their operations. Uses of telecommunications and information technology are critical to this process. The use of Design Build Teams resulted in greater functional integration and less organizational stratification. The use of such teams requires that information technology be integrated into manufacturing, marketing, and service strategies. An additional benefit resulted in organizational changes that promoted teamwork, knowledge sharing, focus on external competition, process orientation, and customer focus. In these days of instant communication and intense rivalry, the use of IT is essential for firms if they wish to remain competitive. Boeing's case study provides other manufacturers with an excellent example of possible deployment opportunities for IT in the process of manufacturing products and in the products themselves. This reinforces the concept that IT is now inseparable from the business.

This paper shows that IS academicians and practitioners need to think "out-of-their box" and understand that IT could be used to improve the manufacturing process in every part of the life cycle. Instead of playing a support role in the company, the MIS division should become a major enabler in improving the manufacturing process and product quality. They need to design the IT architecture and IT tools and let the functional organizations design and oversee the content. Sharing their technical knowledge with end-users will become important in this new environment. The IS division needs to change its focus on computing as the end-all, to focus on customer requirements so that trust can be established between the IS division and other parts of the organization.

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