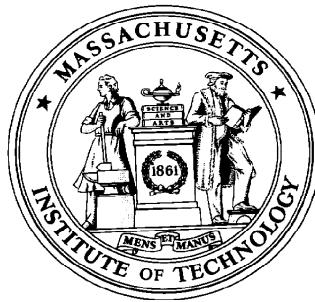


# **LEAN EFFECTS ON AEROSPACE PROGRAMS (LEAP) PROJECT**

## **737 FUSELAGE CASE STUDY REPORT**



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**March 1, 2002**

# 1 INTRODUCTION AND OVERVIEW

## 1.1 Introduction

The Boeing 737 “Next Generation” (NG) is the follow-on to the longest continuous production line in commercial aircraft history. The original 737 (-100) was launched in February of 1965, followed by the -200, -300, -400, and -500 models, and by completion of the “Classic” Program,

in 1993, 3132 737s had been delivered. The Next Generation 737 represented a radical redesign of the aircraft, including the -600, -700, -800, -900, “Combi” (-700C), and Business Jet (BBJ) models, to be superior to competitors such as the Airbus A320 series and the McDonnell Douglas MD-90. The



**Figure 1: Boeing 737 Family (courtesy Boeing Co.)**

airplane falls under Boeing Commercial Airplane Company, which is a subdivision of the Boeing Company. Customers for the aircraft include major airlines around the globe in addition to customers who use the plane for cargo, such as the United States Navy.

## 1.2 Main Findings

The 737 Fuselage story is very impressive. First of all, the plant ramped up production from 10 to 28 planes per month, which in itself is remarkable, but in this time, several other lean principles were set in motion, leading to great improvements. For example, flow time in the factory was reduced by 21 percent, while creating capacity to add work content from the Boeing final assembly plant in Renton, WA. Furthermore from 1998 to 2000, labor hours per unit were reduced by nearly 50 percent. Unit cost was reduced by 25 percent over the same period.

### **1.3 Approach**

A two-day site visit to Boeing Commercial Aircraft Company – Wichita was undertaken in January 2002. The 737 Director of the Structural Value Stream and his staff made formal presentations, plus we had an opportunity to participate in a weekly Review Team Meeting of the Value Stream Production Line Managers. A complete factory tour consisted of reviewing the schedule, cost, quality, morale, and safety metrics at each line location and an opportunity to interview the Production Line Manager (PLM) in his or her workplace.

A two-hour formal interview with the entire Structural Value Stream Organization gave us a chance to present our structured interview questions and derive the benefit of the entire group in formulating the responses.

### **1.4 Organization of the Report**

The remainder of this report will describe the program and product and an overview of the whole picture—the extended enterprise. The study will continue to look at the implementation of lean, including highlights and achievements, enablers and practices, as well as external factors and developments. That is followed by a look at remaining challenges and future opportunities, and the paper is concluded with a section on “lessons learned” and final observations.

## **2 CASE STUDY PROFILE**

### **2.1 Summary Case Study Profile**

The 737 Next Generation Aircraft was a major product “overhaul” to assure continuation of Boeing’s most successful commercial production aircraft, the 737 Classic. With over 3000 aircraft built and sold, and with increasing competition from Airbus with its A-320 family and McDonnell Douglas with its newly introduced MD-90, Boeing conceived of a family of larger 737 aircraft with significantly improved economics for the airlines and longer ranges permitting more city-pairs of destinations. The 737 models 600, 700, 800 and the new 900 have been designed, FAA Certified and sold to the world’s airlines. At

this writing over 1100 Next Generation 737 aircraft have been built with the production line achieving a peak rate of 28 aircraft per month—an absolute industry record for the most pounds of aircraft produced on a monthly basis in the history of commercial aviation. Figure 2 shows the general arrangement of the 737 NG and shows the features and performance. Passenger capacity ranges from 110 to 189, and is capable of ranges of approximately 3000 miles for the commercial passenger planes to as far as 6200 miles for the Boeing 737 Business Jet, known as the “BBJ”.

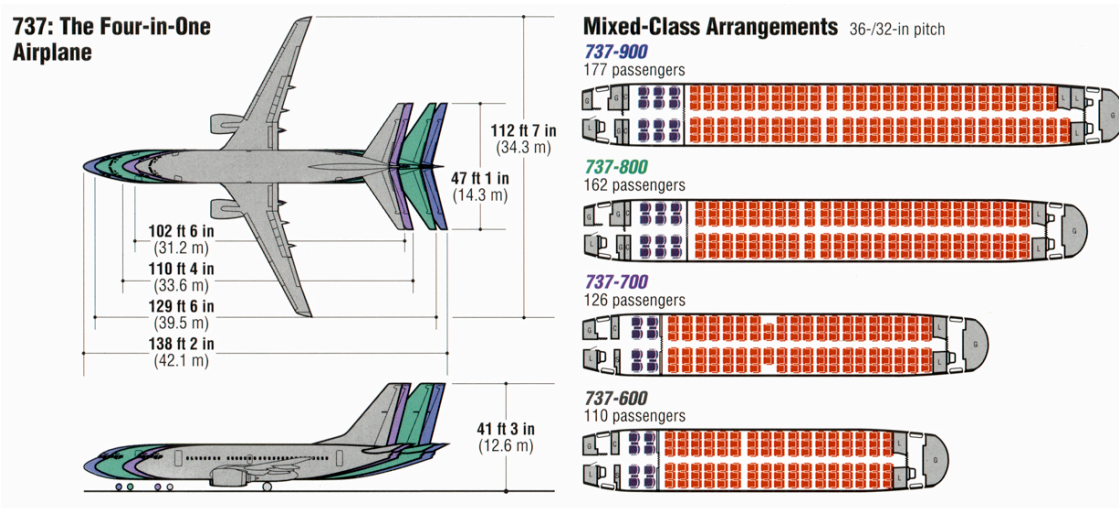


Figure 2: Boeing 737 Features (courtesy Boeing Co.)

## 2.2 Larger Organizational Context

Our case study focused on the 737 Airframe designed and produced by Boeing’s Wichita division. The 737 Structures Value Stream Organization at Wichita consists of all the functional organizations required to design, production engineer, plan, fabricate, procure, assure quality, and assemble the 737 fuselage. Boeing Wichita is one of several significant organizational elements of the Boeing Commercial Airplane Company which is headquartered in Renton, Washington (other elements of the BCA are in Everett, WA, where the 747, 767, and 777 are produced; Auburn, WA for fabrication and machining; Spokane, WA for composite structures; Portland, OR for major machine parts; and Tulsa, OK for major assemblies). The new corporate headquarters for the Boeing Company is in Chicago, Illinois.

The driving forces that lead to huge lean achievements on the 737 were a combination of circumstances. First, Boeing launched the marketing efforts on the Next Generation 737 at the right time, and its overall appeal to the airlines was overwhelming, resulting in a huge sales—and therefore, production backlog. This caused Boeing to have to accelerate the production line to 28 per month, a remarkable task which had never been done by a commercial airplane manufacturer.

Second, Boeing had been working Lean for several years, starting with significant quality and production initiatives including Quality Circles, Continuous Quality Improvement (CQI) and the immense effort to adapt the Toyota Production System (TPS) through the use of the Shinijutsu Consultancy (ex-Toyota executives that taught practical lean concepts by having Boeing executives working for a week on Japanese production lines). The resulting Lean application at Boeing is known as the “BPS”, or the Boeing Production System. For example, “Kaizen events” are known as “Accelerated Improvement Workshops,” or AIWs, allowing for any cultural sensitivity by U.S. workers.

The “Turning Point” that caused the gigantic lean “push” at Boeing Wichita on the 737 was clearly the requirement to be able to meet the very ambitious delivery commitments to the airlines, at the stated price—intended to be on par with the Classic, despite significant improvements. To achieve the very aggressive cycle times, all Lean Principles had to be employed simultaneously!

Wichita’s largest supplier is Alcoa, who provides all the aluminum used for sheet metal skins, forgings, bar stock, plate for high speed machining, etc. One of the key events in Wichita’s lean transformation was the amount of learning the 737 Structures Value Stream Team acquired by working closely with its supplier, Alcoa. Alcoa had forced itself to become lean and had implemented a series of organizational concepts (the “A-3” Value Stream roadmap) for systematic application of Lean including “as-is”, “to-be”, goals, milestones, and metrics and the concepts of “Lean Academies”.

Boeing Wichita aggressively pursued Lean principles to drive the culture change for the entire 737 Program and enlisted the support of organized labor, their local IAM union chapter. They have been so successful in getting total workforce “ownership” and buy-in, that one of the IAM Union Stewards is the Lean Leader in one of the fuselage sections. Workforce training in the Boeing Production System (BPS)—Boeing’s adaptation of the Toyota Production System—is very important, and the extent to which Lean in the various divisions has been formally trained is as follows:

Lean Basics Training	80-90% of 737 Program employees
Employee Participation in Lean Academy	30-80%
Training in Standard Operations	20-60% (Bands represent training across the 7 elements of the 737 Structures Value Stream Organization)

Wichita has implemented a 5 Level Lean Self-Assessment Tool (LESAT), and uses it to determine progress towards 100 percent lean proficiency across the organization. The extensive diffusion of lean principles and the continuous drive for additional improvements through weekly progress meetings and recognition programs are major elements in the success of the 737.

### **3. EVOLUTION OF LEAN IMPLEMENTATION**

#### **3.1 Highlights of Lean Transformation**

The Boeing 737 had a successful heritage, and the Next Generation was no exception. Due to intense aircraft market pressures, as mentioned above, the Next Generation was designed to be more attractive to customers, both from features and cost standpoints. Built upon past success, it was designed to have lower direct operating costs, greater passenger capacity and range performance, all without requiring large non-recurring training, spares, and airport infrastructure costs associated with introducing a new model to the airline. As a result, orders skyrocketed, and Boeing had to commit to a production rate of 28 per month, up from 10 per month. The result was that Wichita was faced with the significant challenge of using every resource available to “climb the hill” of a vast acceleration of production.

Their multi-faceted production acceleration plan involved the following:

Timeline:
1993
• 737 IPTs
• Determinant Assembly Introduction
1996
• Lean Manufacturing
1999
• Boeing Production System
2000
• Value Chain Strategy

1. Pursue building of a more complete aircraft per month by building larger assemblies with fewer parts.
2. Establish “market-driven target costing” (MDTC) as the driver of factory unit cost targets.
3. The use of Determinant Assembly, allowing the power of Computer Aided Design (CAD) to establish necessary geometries for DNC drilled holes with proper tolerances for ease of assembly.
4. Co-located IPT teams, many on the factory floor, with highly visible metrics of cycle time, unit cost, quality, safety, morale, and attendance, among others.
5. Investment exceeding 100 million dollars in capital equipment, including 19 Brotje Ring Riveters, which install more than 90 percent of the nearly 100,000 fasteners on each 737 fuselage, at a rate of more than one aircraft per day. The result is reduced unit labor costs, fewer hole-drilling defects, and superior skin quality.
6. Flexible tooling, to permit rapid transition among the 7 various models of the 737. CATIA-identified NC drilled holes for joining fuselage sections with laser alignment, culminating in the reduction (from large tooling jigs and hand drilling) of at least 10 days in flow time on each 737.
7. A Total Productive Maintenance (TPM) program was implemented using Autonomous Improvement Workshops (AMW) to assure that equipment breakdowns were not a cause of production bottlenecks.
8. The overall business parameter or metric used by the Boeing Company, including Wichita, is Economic Profit (EP). All business decisions are made using the impact on EP as the guiding principle. (See Figure 3)

# Linking the Shop Floor

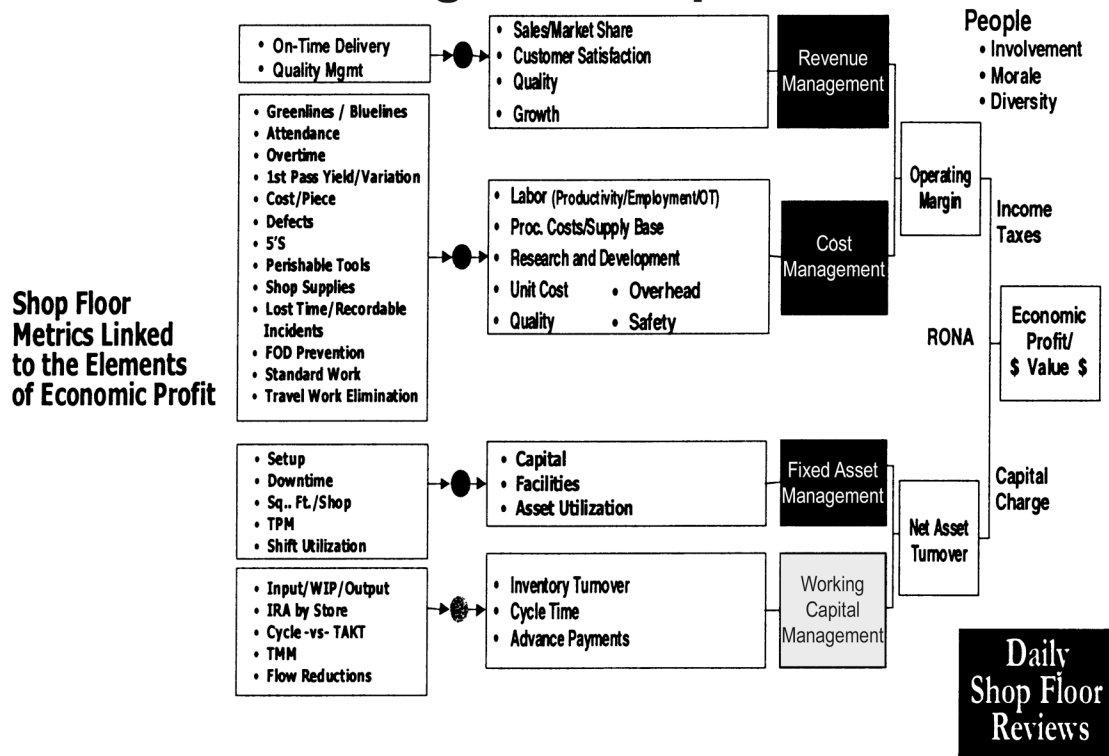


Figure 3: Boeing Economic Profit Calculator

- In addition to large capital investments in machinery, individual “Chuka-Chuka” lines have been inexpensively created to support single-piece flow. One such line produces 1 part every 60 seconds.

The plans were implemented with great success, some of which is evident in the next section.

Although the acceleration of production rate started in the 1997-1998 timeframe, with the initiation of the Next Generation 737, the Boeing personnel we interviewed were clear that the giant steps forward in Lean did not occur until “critical mass” was achieved in terms of (1) Sufficient top down management alignment and (2) Factory employees receiving Lean training and proficiency. There were many steps along the way!

The first of these steps was to initiate a culture change. To do this, a new organizational structure, the 737 Value Chain team, was put in place with a lean savvy team. The organization featured co-located IPTs involving Engineering, Manufacturing, Quality,



and Supplier personnel as necessary, co-located on the factory floor next to their assigned structural assembly section. In addition, a factory design was conceived to handle “mixed-model” production. Not only were entire fuselages of the seven 737 NG variants to be built, but critical sections of the 747, 757, 767, and 777 as well, all of which were accelerating in production at the same time in the same factory at Wichita. Furthermore, new leadership in the 737 Value Chain Organization championed lean, and provided the leadership and encouragement to overcome hurdles and achieve the unprecedented manufacturing rates. Finally, Supplier Chain networks were established, wherein individual suppliers provide *daily supplies* of needed parts and standards directly to the point-of-use in the 737 Assembly Area. “Min-Max” usage concepts are used as are specially designed kits packaged to minimize material handling. These are among many concepts and improvements made across the factory floor and up the chain of command.

### **3.2 Major Achievements**

The result of these initiatives was phenomenal. The 737 Fuselage team was able to achieve some significant firsts. The first Model 900 was introduced at a lower unit cost than the 200<sup>th</sup> Model 800 that preceded it. Most impressive is the learning associated with the new model (see the Unit Time, Appendix A). There are two very interesting things to note about this chart. First of all, note the lack of peaks in the 737 Next Generation (red or lower) line--the introduction of change without an associated “spikes” in the learning curve is unprecedented! Another impressive fact is that despite years of learning on the 737 Classic, the unit time for the 737 from the Classic to the Next Generation was reduced of 40.3 percent at the same unit number. Even the from the final 737 to the new 737 flow time was reduced by 21 percent. Mentioned earlier was the fact that IAM Union buy-in was crucial to success. In order to achieve Takt Time and to preserve the workforce in a period of rapidly decreasing cycle time, 737 factory employees were cross-trained to be able to do more than one operation. Flexibility—even on the individual level—helps achieve lower unit costs and improves quality. With vastly improved modularity and agility in the new factory design, not only is Wichita capable of producing seven different models of the 737 simultaneously, but can incorporate airline specific customization features with as little as a few days

notification. Furthermore, with a reduction in suppliers, and improved supplier relations, major suppliers are providing more immediately useful products to their point of use. Alcoa, for example, now provides all forms of aluminum skins, plates, forgings, bar stock—cut to size—required to fabricate and assemble the fuselage.

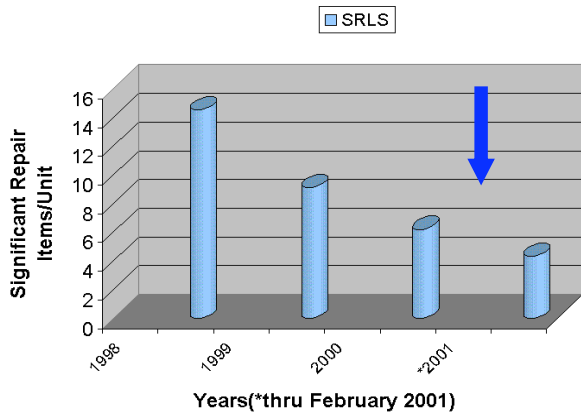


Figure 4: Significant Repair Items/Unit

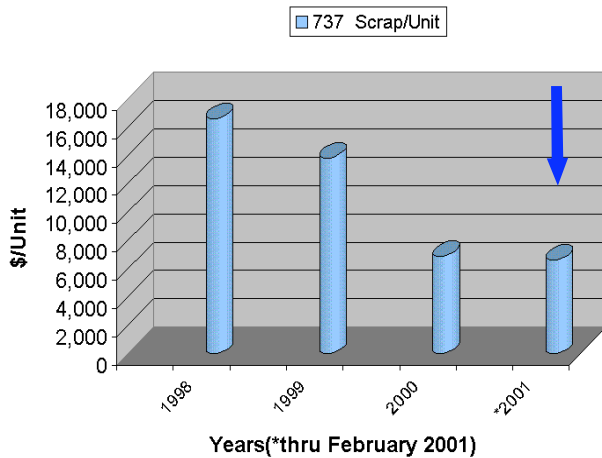


Figure 5: Scrap/Unit

direct measure of quality has been reduced by about 50 percent, along with “Pickups” and Non-Conformance Records, which have dropped by about 40 percent. Since labor is the largest cost in airplane production, it is an excellent metric by which to judge performance. In

Associated with these drastic changes are some undeniable statistics. To achieve the accelerated production rate, *quality had to improve*. With a lot of hard work devoted to root cause identification and corrective action, quality did improve! Significant repair, which is both a disruption to flow time, and indicates an inverse measure of quality, has been reduced by over 50 percent (see Figure 4). Scrap costs, a measure of waste, has been reduced by over 60 percent, as seen in Figure 5. Rework / repair costs, which are perhaps the most

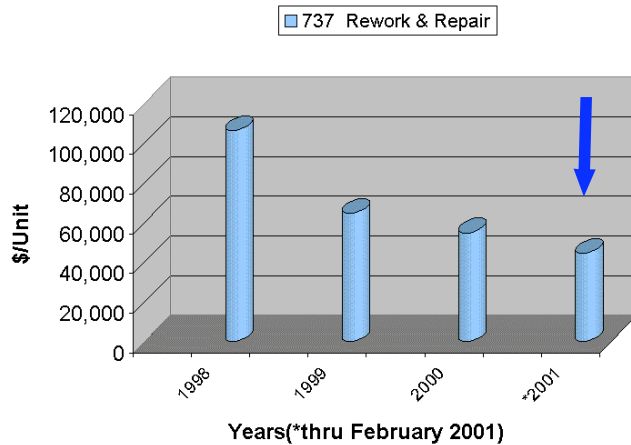


Figure 6: Rework & Repair

this department, there has been significant reduction, which can be seen in Figure 6. Perhaps the most impressive statistics are from the Total Unit Cost, which is the culmination of all the lean practices that Wichita has put in place. As shown in Figure 7, not only has the total unit cost come down

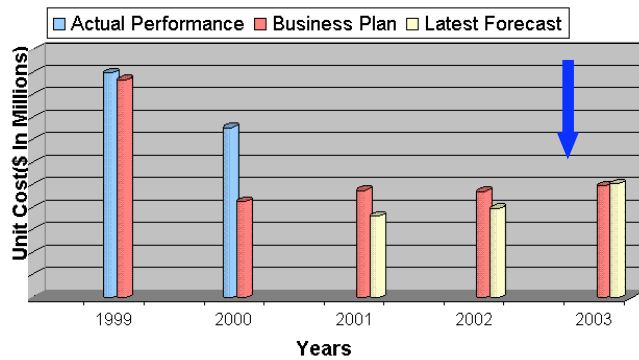


Figure 7: Unit Cost

significantly, but also forecasts indicate that Wichita will continue to improve beyond already aggressively low targeted costs.

### 3.3 Key Enablers, Processes, and Practices

Along the road, there were some significant essentials to lean. Some of the major overarching elements of the 737 Next Generation fuselage assembly line included:

- The vision of a high rate production line building *fewer, larger assemblies* than ever had been



accomplished before. The single-piece total fuselage that is made in Wichita and shipped on a special freight

car to Renton, WA is the singular example of the extent of this concept. (See figures to see how reduced cycle time in final assembly was achieved by driving the sealing operation and fuselage



“shake” inspection upstream in the production line. Work-in-progress airframes in final assembly were reduced from 6 fuselages to 1 fuselage as the achieved 28 per month production rate.)

- The extensive use of CATIA design with the application of Determinant Assembly, permitting the use of low-cost flexible and rapid setup tooling was a key factor in achieving a 28 per month rate of mixed 737 models.
- Co-located IPTs with all functional disciplines located on the factory floor to support manufacturing enhanced both communication and teamwork.
- A new organization, spearheaded by a strong “Lean Champion”, provided the leadership for lean transformation.
- A human resource environment that permitted and encouraged freedom of thought and allowed all employees to rise to the challenge and “own” the ambitious goals and contribute to lean implementation with their individual expertise, was extremely important to the attainment of low unit costs per pound of airframe that had never been seen before.

As a result of all these changes and new implementations, the 737 Next Generation was not only able to live up to its heritage as the world’s most popular airplane, but set a new precedent in aircraft production.

The enterprise is extensively involved in this. Boeing Corporate starts the process with a value assessment and moves that business plan down through the organizations (of which Wichita is one) and to the programs (the 737), which are responsible for achieving continuously improved metrics year after year. A Boeing corporate Value Scorecard, which is varied depending on the program, measures the results monthly.<sup>1</sup> Executive performance is evaluated in this Value Scorecard with rewards and recognition based upon achieved goals.

### **3.4 External Factors and Developments**

The commercial aircraft industry is very competitive. When the 737 Next Generation was first set in motion, there were three (3) aircraft vying for the same market—the 737 Classic, the MD-80, and the Airbus A320 series. In addition, 1993 marked the first

launch of the MD-90. Both the A320 and MD-80 had been around since the mid-1980's, while the 737 had been around since the late 1960's. Despite numerous models and upgrades, the pressure was on Boeing to challenge the newer airplanes from McDonnell Douglas and Airbus. The result was a completely new 737, with customer involvement continuously throughout the design process. Combined with the low cost and improved economics, the popularity of the airplane forced Boeing to commit to a production rate of 28 per month, neither of which would have been possible without lean principles. One of the key factors in motivating the low cost was a shift in airline customer focus. Airline deregulation of ticketing throughout the 1980's and 90's resulted in major airline emphasis on up front acquisition costs, as well as low direct operating costs.

## **4 REMAINING CHALLENGES AND OPPORTUNITIES**

### **4.1 Remaining Challenges**

In the aftermath of September 11, 2001, and the consequent backlash in the airline community, several airlines approached Boeing and negotiated extended delivery schedules. The result is that the Wichita plant no longer has the immediate demand to produce 28 planes per month, and is currently in the process of “downshifting” to a production rate of 14 per month. One clear challenge will be to maintain unit costs throughout this period. Behind this challenge, there are many different considerations, such as cautious overhead adjustments, and acquiring more work in Wichita (including electrical wiring, hydraulics, environmental control systems) to minimize workforce reduction. The benefit of doing so is a reduction of flow time in the Renton final assembly line.

### **4.2 Future Opportunities**

Boeing's 737 Next Generation is a great accomplishment, not only from the market strength of the airplane itself, but also in its wildly successful implementation of lean principles and practices. Boeing Wichita has demonstrated effectively that its management and workforce have mastered the key principles of Lean and have made major breakthroughs in the production concepts of commercial aircraft. While applying this to other portions of the 757, 767, and 777, the Wichita management is keenly aware

that they can be a major player in the proposed Boeing Sonic Cruiser. In addition, the military side of Wichita, not studied in this trip, can apply many of the Lean principles to their major military modification programs on the KC-135, B-52, and C-17 aircraft.

Not only can the entire Boeing company learn from the success of the 737 program, but the 737 program itself has identified regions to improve. They are presently attempting to create an assembly line based on “pull” instead of schedule.

### **4.3 Lessons Learned**

An emergent theme throughout many Lean success stories, including automobile, electronics, and aircraft, is that major breakthroughs have resulted from a “crisis situation”. So too, in the case of the 737, Boeing found itself with a giant order backlog that required unprecedented production acceleration to fulfill market demands. Wichita rose to the challenge with a mighty effort involving the entire organization. Boeing management was smart enough to realize they needed to “install” a new seasoned team, trained and committed to Lean. It worked!

### **4.4 Concluding Observations**

This study of the 737 fuselage identified the transformation of an “old-line” manufacturing organization that already had a reputation for building excellent airframe structures into an even better, “world-class” manufacturing organization that has set new records for low unit cost, lowest cycle time ever achieved in the commercial aircraft industry, and superior quality. This transformation could not have happened without the comprehensive application of Lean throughout the Structures Value Stream Organization. In addition, key leadership at the top is a common ingredient in all Lean success stories, and it was proven again in Wichita.

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<sup>i</sup> 737 Structures Center, Kansas Award for Excellence Level III Application, May 31, 2001