

Transforming Data into Information to Control and Improve a Ribbon Bonding Process

by

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B.S., Mechanical Engineering
Georgia Institute of Technology, 1996

Submitted to the Sloan School of Management and the
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and
Master of Science in Mechanical Engineering

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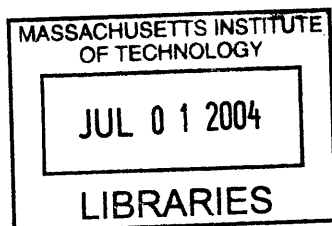
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ABSTRACT

In a complex production process attached to every unit are considerable quantities of data that provide many details regarding process performance. On many occasions, although this data is collected in a database or in some cases manually, output is never generated from this data. Often the data is reviewed by operators or engineers but because of its complexity no real conclusions are drawn from it and hence the data is never used to take action or make appropriate decisions.

This work explores the theme that the use of information transformed from data is critical in making the necessary decisions and actions in a problem solving process. This methodology is carried out in solving significant yield and rate problems of a ribbon bonding process used to produce state-of-the-art surface radars at Raytheon Company. Transforming data into information particularly through the use of visual tools became essential in determining root causes by bringing forward underlying issues. This led to increased confidence in making the right decisions and ultimately led to implementation of process improvement solutions.

Work for this thesis resulted in several process improvement initiatives as well as the implementation of an automated data management tool designed using extensive visual controls to provide real-time process feedback to operators. The process improvement initiatives involved implementation of a new cleaning process prior to ribbon bonding as well as the design, manufacture, and implementation of a work stage that added heat to the bonding process. These process improvement initiatives resulted in the elimination of the yield and rate problems and led to cost avoidance savings of over \$2.6M for the first two radars. More importantly, the lessons learned from the methodology introduced in this work and used to solve ribbon bond process problems will lead to lower production costs on all future radars.

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1 Introduction

The focus of this chapter is to provide a framework for a better understanding of the cultural and manufacturing conditions existing at IDS Operations – Andover Campus, recently renamed as Raytheon IDS’ Integrated Air Defense Center, over the six months of this work. It begins by first providing an overview of the plant culture, then presents a technical problem - which represents the main focus of this work – and concludes with the challenge required to change the existing conditions and culture essential in solving the problem at hand.

1.1 The Andover Norm

Raytheon Company, founded in Cambridge, MA in 1922 first began building radars for the defense industry during World War II. Twenty five years later, after many successful introductions from microwaves to missile guidance systems, Raytheon was awarded by the Army the “Patriot” Air Defense System contract. Over the next twenty years over 150 firing units (radars and command/control centers) and 9000 missiles were produced. The Integrated Air Defense Center, located in the heart of Massachusetts’ Merrimack Valley, was initially constructed in the 1970’s to provide manufacturing support for the Patriot program. In the heart of Patriot missile production in the late 1980’s to early 1990’s, the Integrated Air Defense Center experience continuous multiyear production of Patriot hardware. While this time represented a very successful period for both Raytheon and the Integrated Air Defense Center, it also served to engrain a culture at the facility. Even at peak periods (representing an output of hundreds of units per month) during the Gulf War, the facility still represented a relatively low-volume manufacturing culture. On the factory floor, production output was presented on the scale of months. Final product deliverables were looked at as individual units and factory floor management systems consisted of pieces of paper that traveled with each product. In the management offices, the same low-volume cultural effects could be seen. Decisions were relatively slow to be made as any process change typically affected a relatively few number of units versus thousands as would typically be seen in a high-volume culture. Today this same culture still exists in the facility and with the introduction of a new “high-volume” product line¹ a cultural change at the design, manufacturing, and management levels is required to succeed.

¹ The focus of this work occurred on a complex microwave product requiring the production of 30 identical units/day which, relative to the existing plant culture, can be defined as “high volume.”

1.2 *Ribbon Bonding Problem*

As part of the next generation of missile defense, IDS Operations/Andover is highly involved with the production of large phased array solid-state radar. Unlike product lines of the past at this facility, this product requires a relatively high volume of production as a result of a design consisting of thousand of identical subassemblies which make up one larger assembly. In order to meet the required demands the use of precision automated equipment has become necessary. One of the processes chosen to be automated is the critical circuit interconnect process of gold ultrasonic ribbon bonding. In this process an automated ribbon bond machine places approximately 200 individual ribbon bonds down between microwave interconnection circuits. Significant variability in the process of ribbon bonding in combination with the small bonding window produced by the constraints at the component level resulted in very low first pass yields at both initial inspection and test. This low yield resulted in extensive rework and inspection which made it nearly impossible to make the required production rate. As a result a team was established to develop solutions to widen the process window, bring the process into control, and in effect increase machine yield and process throughput. This work focuses on the approach the team took to perform root cause analysis, solve the existing problem, and set in place a framework to continuously monitor and improve performance in the future.

1.3 *Data Management Systems*

Due to the multivariate nature of this problem one of the most critical factors in solving the problem was the collection of relevant and accurate data. Stemming from the low-volume cultural norm currently instilled at the Integrated Air Defense Center, an accurate and efficient means of real-time data collection and management was essentially non-existent. The standard method of data collection involved either hard copy data collection (i.e. paper data printouts either filed at an operation or routed with the unit) or entry into text based fields in the shop floor data management system. In the past this level of collection was good enough since the amount of data required to be collected was small and process cycle time adequate to accommodate. However, with a ribbon bonding process that involves hundreds of ribbons experiencing numerous process steps on thousands of units per month, this method of collection can not serve the needs of the operation. Thus, in order for the team to understand what was really happening and to make process change decisions based on the data, it became essential not only to develop new systems of data collection but first and foremost to gain an understanding of what types of information needed to be collected. One of the significant outcomes of this work was the author's development and implementation of data collection and analysis tools. Additionally, the

accomplishments achieved in this work have heightened the awareness of the need for data collection improvements and as a result several follow-on projects are currently in the works.

1.4 A Need for Turning Data into Information

One of the major challenges faced by the team is that they were presented with a process that is affected by many variables with dynamic interdependencies which are not well understood and thus difficult to bring consistently under control. Prior to the start of this work the team was aware of this challenge and as a result understood the need for data collection. However, in a process such as this the task of data collection can be overwhelming and if not organized properly, the data becomes useless (Eisenberg and Jensen, pp.61). Essentially this is what was occurring. Lots of data was being taken and stored in various means, but for months the team struggled to move forward because the data wasn't effectively used to help move the problem solving process forward.

As a result it became very evident that in order to make use of the plethora of industry knowledge and experience that existed in the team and move forward in solving the problem it was critical for the team to make meaningful use of all of this available data. In addition to the tangible factors of production – material, capital, labor, and product - one less tangible but equally important resource exists – information – which manufacturing systems both produce and consume (Smith, pp. 15). Putting these two thoughts together it is apparent that there is a need to turn available data into information. In a situation such as solving a multivariate technical problem, information plays two important roles. First of all, it is essential in determining the root cause by bringing forward underlying issues by making sense of what is really occurring. Secondly, it plays a critical factor in the decision making process by driving decisions and providing the necessary buy-in from the organization once the decisions are made. Throughout this work it is apparent the vital role this transformation of data into information plays in ultimately driving the end solution as well as leading to the development of systems and thinking that make for better decision making in the future.

In summary, the major accomplishments of this work exemplify how the transformation of data into useful information led to revolutionary improvements in the ribbon bond process as well as set the stage for continued evolutionary improvements in the future.

1.5 Thesis Structure

Chapter 1 provides a framework for a better understanding of the cultural and manufacturing conditions existing at IDS' Integrated Air Defense Center over the six months of

this work. It begins by first providing an overview of the plant culture, then presents a technical problem - which represents the main focus of this work – and concludes with the challenge required to change the existing conditions and culture essential in solving the problem at hand.

Chapter 2 provides insight as to how a new product line of upper tier missile defense system mechanisms in the form of state-of-the-art surface radars has forced a new way of operational thinking and doing at the Integrated Air Defense Center.

Chapter 3 presents how the surface radar line has brought ribbon bonding to another level in its use in a large area application. It begins by providing a brief history and discussion of ribbon bonding and then focuses on how this next generation of ribbon bonding presented significant challenges for Raytheon and the surface radar line.

Chapter 4 discusses how one of the major hurdles to operating an efficient and quality “high-volume” manufacturing line has been the effective use of a data management system. It focuses on the current data management systems and provides recommendations as well as begins to discuss an initiative taken to improve the ribbon bond process’ means of data collection and analysis.

Chapter 5 focuses on how use of a methodical approach led to the elimination of the ribbon bond problem. Furthermore, it delves into how, by overcoming the ineffectiveness of the data collection and management system, utilization of visual tools became the critical element in determining the root causes, measuring process capabilities, and driving decisions. Additionally, imbedded in the discussion of the problem solving approach, is a description of the two major technical initiatives that led to the overall ribbon bond process solution and significant cost savings on the surface radar line.

Chapter 6 introduces a statistically efficient and economical method of performing optimization through a design experiment (Montgomery, pp.4). It is written as a case study and provides an example of how the successful design and execution of a design of experiments (DOE) led to the optimization of the ribbon bonding process parameters.

Chapter 7 focuses on the importance of real time informational feedback in both monitoring and improving a manufacturing process. The chapter begins by discussing the importance of process control and the use of it at the Integrated Air Defense Center. It then provides a detailed look at a system designed and implemented during this work to provide ribbon bonding process monitoring. The chapter concludes with a discussion of the positives and negatives of this system and the future of real time monitoring on the ribbon bonding line.

Chapter 8 shifts focus a bit as it looks at the softer side of the process improvement changes that took place at Raytheon and in the ribbon bond room. The chapter, with portions

written in the first person, reflects on the author's experiences during this work and how organizational processes affected how change was made. By analyzing the importance of good team dynamics and the organizational structure being affected by change we are better able to understand the contributing factors that led to success over the course of this work.

Chapter 9 provides concluding thoughts that summarize the institution of change leading to an improved ribbon bond process and many lessons learned. It focuses on a discussion of the key element of this work transforming data into information and the potential for continued use of this methodology. It concludes by providing an update of the ribbon bond line three months after the conclusion of this work and gives examples of how the lessons learned from this work have been critical in continued improvement of the process.

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2 A New Type of Product

As we enter into a new warfighting era focused on integrated ballistic missile defense systems, Raytheon has been awarded several contracts to provide an upper tier missile defense system mechanism in the form of state-of-the-art surface radars (see figure 2.1). The chapter provides insight as to how this new type of product has forced a new way of operational thinking and doing at Raytheon IDS' Integrated Air Defense Center in Andover, Massachusetts.



Figure 2.1 – Phased-Array Radar System

2.1 *Surface Radar Product Line*

Over the last several years Raytheon has become a leader in the design and manufacture of complete integrated weapon systems. Due to the large scope and enormous price tags on these systems, even in full production only one or two systems are built each year with each individual system typically requiring approximately two years to produce. Thus, looking at the product line from the complete system perspective these weapon systems fall in line with a traditional low-volume production culture. However upon breaking down an integral part of the system, the phased-array solid-state radar, into lower subassembly levels it becomes apparent that the manufacture of these radar arrays² is quite different from a low production rate norm.

The front end antenna of the phased-array surface radar system is made up of several thousands of identical complex radar subassemblies. In over twenty process steps, each of these subassemblies is built up from component level parts. Because these subassemblies represent large volumes of identical parts going through numerous process steps, the manufacture of these subassemblies takes place in an assembly line fashion on the factory floor. An assembled subassembly is approximately 24" x 6" and weighs over 6 lbs. This subassembly will be referred to as the "radar unit" over the course of this work.

² The front end antenna subassemblies of the phased-array solid-state radar are manufactured and assembled at the Integrated Air Defense Center.

2.2 High-Volume Manufacturing

As with most defense contracts which operate on a cost plus basis meeting the contractual delivery dates is critical to achieving cost and schedule metrics. The surface radar product line falls into this category and thus factory floor production rates are driven by delivery requirements. In order to produce the volume of radar units necessary for a given radar a daily production rate of approximately 20 radar units is required. When compared to a high-volume manufacturing company such as microprocessor company who may produce 20,000 chips a day from a single line this may seem like low volume. However, to Raytheon and in the defense industry in general, this represents high-volume manufacturing.

Being suddenly exposed to a high-volume environment brings many challenges to a low-volume culture. Some of the most prominent issues include the struggle in development of designs that can be manufactured in high-volume processes, data management of thousands of process steps, and the need for real time decision making. In the fall of 2002, when IDS Operations/Andover transitioned from the design to the manufacturing stage of this new surface radar product line each of these challenges immediately presented themselves and in spite of deliberate preparation activities, the planned rate of 20 units/day was not initially met. Nonetheless, with the path of least resistance not being the slipping of delivery dates, the radar unit line initially laid out to achieve daily required rates of 20 units/day has seen unachievable required rates up to 77 units/day. Today this area routinely achieves 30 units/day on a continuous basis. It operates ahead of schedule and under budget. One of the enabling process accomplishments leading to this success is discussed as the subject of this work.

2.3 Automated Ribbon Bonding

One of the biggest challenges IDS Operations/Andover has faced with this new high-volume surface radar product line is successful design for manufacturing. One of the critical aspects of the radar unit is the method of signal interconnect between transmit and receive modules and the rf components. During engineering and design it was determined that the best method of interconnect would be gold ribbon bonding. Gold ribbon bonding won over other bond types and single piece interconnects because of its automation capability and the proven reliability of gold on gold bonds. However, one the major drawbacks of this design is that it requires the placing of 184 individual gold bonds as opposed to a single piece interconnect.

A standard method of performing ribbon bonding and one that IDS Operations/Andover is familiar with is through use of a semi-automated ultrasonic wedge bonder (Figure 2.2 is a picture of the Westbond 4530E series bonder used at the Integrated Air Defense Center).

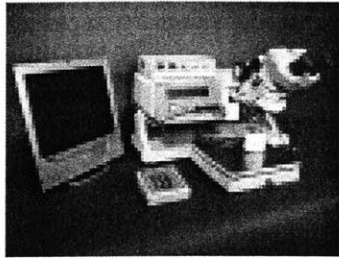


Figure 2.2 – Westbond 454630E Semi-Automated Bonder

Semi-automated Westbond machines have been used successfully in other product lines at the Integrated Air Defense Center. Standard operation of these machines requires an operator who manually selects the locations of the first and second bond sites for each individual bond while the machine automatically applies the preset force and ultrasonic power. A highly trained operator can bond at a rate of approximately 2 quality bonds/min on a semi-automated bonder. With the introduction of a high-volume product line that consists of a design that requires in excess of 500,000 ribbon bonds per radar it was determined that use of these semi-automated machines was no longer feasible.³ In order to successfully manufacture these radar units at the high-volume required rate of 20 units/day a fully-automated, high quality ribbon bonding process was needed.

An automated ribbon bonder that bonds on product the size of the radar units was not currently available in industry. Therefore, Raytheon worked with Palomar Industries to develop a large-scale, state-of-the-art fully automated ribbon bonder. The Palomar 3470-II is a thermosonic wedge bonder that enables deep access wedge bonds across the industry's largest bonding area.⁴ The bonder utilizes X-Y robotic positioners and Advanced Cognex vision pattern recognition system to provide precise loops and wire control. Figure 2.3 is a picture of the Palomar 3470-II automated ribbon bonder and Figure 2.4 show a detail of the bonder tool. In theory the Palomar 3470-II can automatically bond all 184 ribbons on up to four radar units at a time with one press of a button. With this speed a radar unit can be bonded in less than 15 minutes thus easily meeting the daily production demand.⁵ In addition, compared to the semi-automatic Westbonder the fully automated Palomar provides a 75% standard labor savings per radar unit. However, as with any multivariate process that may work under ideal theoretical conditions, given actual real

³ The surface radar production line works a two shift schedule. Thus at a rate of 2 minutes/bond (assuming 6 working hours per shift) < 10 radar units could be bonded per day.

⁴ See <http://www.palomartechnologies.com/products/wb/3470ii-news.htm> for press release.

⁵ At a rate of 15 minutes/unit over 30 radar units can be bonded per day.

life conditions, complexities are bound to arise thus complicating the process. Although initial machine qualifications runs were performed and passed, actual bonding of production parts exposed to real processes presented less than promising results. The remainder of this work details efforts taken to overcome the challenges the automated ribbon bonding process presented to the surface radar production line.

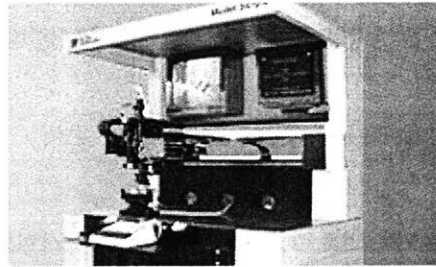


Figure 2.3 – Palomar 3470-II Automatic Bonder

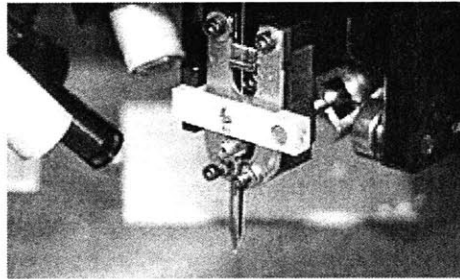


Figure 2.4 – Palomar 3470-II Bond Tool

3 A Different Type of Ribbon Bonding

When Raytheon chose to use ribbon bonding as their method of interconnect on the radar units for the surface radar line they were not walking into to an unproven, unused technology. Ribbon bonding has been around for decades particularly in the microelectronics industry and has even been long used by Raytheon as well. However, the surface radar line brought ribbon bonding to another level through its use in a large-area application. This chapter begins by providing a brief history and discussion of ribbon bonding and then focuses on how this next generation of ribbon bonding presented significant challenges for IDS/Andover Operations and the surface radar line.

3.1 *Thirty Years of Wire Bonding*⁶

In 1989, George Harman published his first edition to what many refer to as the bible of wire bonding, Wire Bonding in Microelectronics: Materials, Processes, Reliability, and Yield. At that time wire bonding had been around for over twenty years and the book was written with the focus on educating a growing industry. By the time the second edition was published in 1996, there were about 4×10^{12} wires bonded per year on the planet (Harman, pp.1) and these numbers continue to grow. Companies having a history of wirebonding technology use include many major microelectronic companies such as Motorola, IBM and National Semiconductor as well as companies such as Rockwell Avionics, Westinghouse and Raytheon. As today's applications consist of production runs on hundreds of devices, the challenge has become to not only master this complex technology but also to do so in a high-volume, low-cost environment (Qin, Reid, Werner, Doerr, pp. 2).

3.1.1 *Typical Wire/Ribbon Bonding Applications*

Wirebonding is used in many different applications including telecommunications, datacom, aerospace, and defense. Most are used in the approximately 40 to 50 billion IC's produced, but many more are in transistors, LED's, etc. The majority of these interconnects occur in the semiconductor business who makes nearly 3 to 4 trillion wire interconnections per year (Harman, pp. 1, 242). A typical semiconductor chip may consist of hundreds of similar bonds placed over a small scale bonding area.⁷ Despite its consistency, wirebonding is still the largest yield detractor in the production of hybrid assemblies. This seeming contradiction can be

⁶ Ribbon bonding is a form of wirebonding that utilizes ribbon over round wire with its advantages being its lower high-frequency impedance and inductance and greater bond reliability. In 1969 investigation of using Al and Au ribbon for wedge bonding began (Harman, pp. 31-32).

⁷ Today the average semiconductor chip measures approximately 2 in².

attributed to the fact that the number of wires greatly exceeds the number of other components, thus providing far more statistical opportunities for failure. (Eisenberg and Jensen, pp. 61). In the early years of ribbon bonding failures occurred about 1 in 100, however with the growing demand for high-quality, low-cost interconnects the industry has reduced its yield losses from 1000 down to 50 ppm.

3.2 What is Wire/Ribbon Bonding?

Automatic gold wire/ribbon bonding is a high-yield interconnect process that uses a combination of heat, force, and/or ultrasonic energy to form a metallurgical bond. Typically, high purity (99.999%) gold wire or ribbon is used to bond to a high purity gold pad.

3.2.1 A Brief Technical Description of Wire/Ribbon Bonding

Many different varieties of wire bonding are common in the industry from thermocompression ball bonding to thermosonic wedge bonding. The Raytheon surface radar line uses thermosonic wedge ribbon bonding. Thermosonic wedge bonding, begun in 1970, combines ultrasonic energy with heat to produce a bond. The radar unit bond is formed by a 1X10 mil Au ribbon threaded over a wedge shaped heated Titanium Carbide Tool. As the tool is lowered onto the Au bond pad low frequency (60 kHz) ultrasonic energy is applied at a given force for a given period of time. The ultrasonic energy helps to disperse contamination at the beginning of the bonding cycle and in combination with the thermal energy matures the bond. The actual metallurgical bond is produced as a result of a deformation weld produced by the softening of the material caused by the two types of energy. Several parameters must be defined prior to bonding to accomplish desired design geometric requirements as well as reliable bond strength. These parameters include tool temperature, ultrasonic power, force, bond time, loop width and loop height. Figure 3.1 is an example of several ribbon bonds bonded on the radar unit.

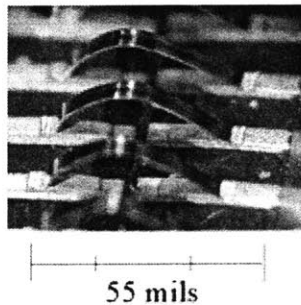


Figure 3.1 – Radar Unit Ribbon Bonds

3.2.3 *Destructive and Nondestructive Testing*

An important metric in ribbon bonding is the determination of the strength of the bonds as measured in grams-force. By measuring bond strength both bond yield and reliability problems can be evaluated. The wire bond pull test is the most universally accepted method used for controlling the quality of the wire bonding operation (Harman, pp. 67). There are two forms of this test destructive and nondestructive testing. Destructive testing is used to measure bond strengths, evaluate bond strength distributions, or determine compliance with specified bond strength requirements whereas nondestructive testing is used to reveal non-acceptable wire bonds while avoiding damage to acceptable wire bonds.⁸ The test is performed by a semi-automated pull test machine which places a hook under the center of the bond and then travels in an upward motion until failure occurs for destructive tests or until a prescribed force for nondestructive testing is reached. Figure 3.2 is the Royce 552 pull tester used on the radar unit line.

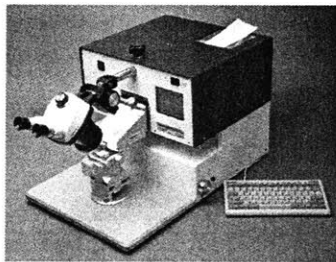


Figure 3.2 - Royce 552 Pull Tester

3.2.4 *The Bonding Window*

There are several different modes of failure that can occur during the actual bonding process (see Figure 3.3 for physical description of typical bond failure areas). The three most common forms of bond failure include overbonding, substrate damage, or no-sticking. Overbonding occurs as a result of too much ultrasonic power and/or force causing the gold ribbon to spread too thin producing a weakened bond heel. Substrate damage occurs due to excessive ultrasonic power resulting in the tool damaging the pad. Lastly, the most common failure mode seen on the Raytheon radar units is bond no-sticking. In this case the ribbon never forms a bond with the pad and thus lifts upon placement. There are many possible causes for this occurrence, but from a bonder parameter perspective the cause is most often inadequate ultrasonic power and/or bonding force.

⁸ As defined by MIL-STD-883E.

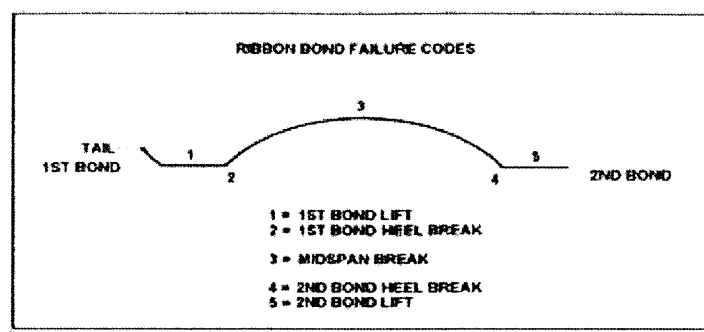


Figure 3.3 – Bond Failure Areas

From this discussion of bond failure mechanism it can be concluded that bonding requires an accurate and precisely controlled combination of the above mentioned parameters and others (Eisenberg and Jensen, pp. 61). Graphically this combination results in an area of optimal settings commonly referred to as the bonding window. Figure 3.4 represents an example of a bond window presented graphically as taken from Harman (pp. 210). While ultrasonic power and bonding force are the common parameters that define the two dimensional bond window in Figure 3.4, in reality many different variables play a part in defining the shape and size of the bond window.

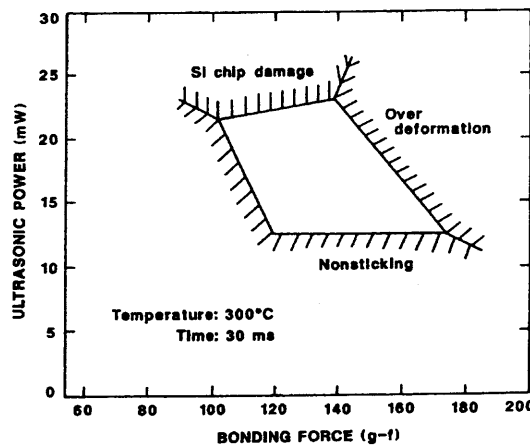


Figure 3.4 – Example Bond Window

3.3 *Ribbon Bonding on a Large-Scale Radar System*

The actual process of forming a metallurgic bond on a Raytheon radar unit is no different than what the rest of the microelectronics industry does on a daily basis. However, there are many unique features on the radar unit that bring a whole new set of variables to the ribbon bonding process.

3.3.1 Large-Area Ribbon Bonding

The most apparent feature that separates the ribbon bonds on a Raytheon radar unit and those on the billions of IC's produced yearly is the area upon which the bonds are placed. Compared to the 2 square inches of area the bond tool travels when bonding an average semiconductor chip, the bond tool on the Palomar 3470-II used to bond radar units travels over an area of 633 in² (4089 cm²). This size area is dictated by the 2' X 6" units that house these interconnections.⁹ This large area requires much greater tool precision positioning and control to maintain bond repeatability. However, the large area also brings new variables to the table such as tool movement and larger cycle times. In addition to a large bonding area, the actual bond geometries are greater than those seen in standard ribbon bonding. While this can ultimately produce a stronger bond and thus higher process yields due to large amounts of gold, there is also a larger risk for organic contamination at the bond site.

3.3.2 Stretching of Limits Results in Small Bond Window

As discussed in section 3.2.1 there are many variables that serve to determine the size and shape of the bonding window. Each time the design brings a new variable into the picture or affects existing variables the size of the bonding window becomes further challenged. Due to its uniqueness in design and application, the radar unit stretches the limits of the standard ribbon process. As a result, given the initial design, the Raytheon ribbon bonding process has been plagued with a very small bonding window.

A major parameter that commonly makes up the third dimension of the bond window, bond temperature, was a variable that was initially treated with caution. Precision RF components on the radar unit are susceptible to elevated temperatures thus any form of heat exposed to the radar unit must be localized and controlled. Benchmarking studies unanimously show that more effective bonding occurs at elevated work stage temperatures¹⁰ and accordingly the size of the bond window is directly proportional to bond temperature. Nevertheless, upon initial transition into manufacturing of the radar unit it was determined that using a heated stage would be too costly and too difficult to accomplish given the current design.¹¹

From a mechanical design perspective there are also many features that lead to a narrowing bond window. One of the more obvious contributors, the large scale bond area, brings

⁹ The actual bonding area is 2" x 6", however the bonder has the capability to bond 4 radar units fixtured side by side.

¹⁰ Both benchmarking studies internal to Raytheon and externally, including industry standards and technical references, indicate work stage temperatures >100°C are commonly used.

¹¹ Although the work stage is not heated, the bond tool is heated to 130°C on the Palomar 3470-II.

new variables to the ribbon bond process such as increased potential for movement during bonding. An example of a mechanical design issue greatly affecting the no-stick region of the bonding window is the cantilevered fastening of a bonded component. While the cantilevered design is necessary given other design constraints it results in decreased rigidity at the bond site thus ultimately affecting the application of bonding force. Other design tradeoffs indirectly affecting the bonding window include loop profiles optimized for electrical performance rather than bond reliability and the importance of bond pad gold purity on bondability versus the cost of eliminating impurities.

Lastly, arguably the most significant variable affecting the bonding window is contamination of bonded surfaces. Wire bonds cannot be made at a high yield unless the bonding surfaces are clean (Harman, pp. 181). Contaminants, if of the right source and quantity, essentially eliminate the bonding window by inhibiting bondability. The significance contamination has on bondability and/or reliability had been initially underestimated in the ribbon bonding of radar units thus further narrowing the bonding window if at times not eliminating it completely.

3.4 Radar Unit Bonding Difficulties¹²

With so many controllable and uncontrollable variables having a part in the bondability and reliability of the ribbon bond process, low process yield issues are not uncommon. Exacerbate this with a narrowing bonding window and the risk of failure becomes even greater. As production on radar units ramp towards rates necessary to meet contractual requirements, the surface radar line has experienced costly ribbon bond process yield problems. Although pre-production qualification of the Palomar 3470-II provided promising results on sample production parts, similar results were not being achieved during full production.

3.4.1 Failures during Bonding

Ribbon bond process problems began at the very first step in the ribbon bonding process, automated bonding on the Palomar 3470-II. The most significant problems occurring were bond no sticks or as explained previously failure of the gold ribbon to form a bond with the gold bond pad. Out of 184 ribbon bonds being placed down on each radar unit, on average approximately 20 ribbons did not stick to the substrate. Additionally many other failure modes were often present such as overbonds, tool impressions, and excessive ribbon tails. Accounting for all types

¹² All numerical yield and performance metrics presented in this section represent data for the month of June 2003.

of failures, a typical radar unit required reworking of approximately 27 ribbon bonds (85% yield). (To further emphasize the severity of the problem, this yield meant rework was required on 100% of the radar units.) Not only did these failures lead to added touch labor time in the form of rework, but also resulted in larger automated bonding process cycle times due to the operator continuously having to stop to rethread the ribbon. Thus, on a machine that is designed to bond four consecutive radar units at essentially the push of a button, only one was able to be done at a time and involved continuous monitoring and intervention.

3.4.2 Failures at Electrical Testing

In addition to the significant number of bond failures described in section 3.4.1 found at first pass visual inspection and routed immediately for rework, a number of unreliable bonds made it past this inspection and eventually failed during radar unit initial and final electrical testing.¹³ In these instances it was more than likely that during the automated bonding process a weak bond was made; a bond strong enough to initially stick but not strong enough to survive thermal and vibration testing. Evidence of “weak” bonds is found in the destructive pull test results.

Destructive sampling was performed on four pre-selected bonds on every other bonded radar unit. Mean pull strength for these ribbons was 77 grams-force with a standard deviation of 30. A metric often used by industry and adopted at Raytheon during this work is the number of sigma from MIL-STD specification failure. In addition to providing a measure of bond process capability this metric can also be used to predict the number of weak bonds. Assuming bond pull strength data exhibits normal distribution characteristics,¹⁴ this value of sigma is used to estimate the number of bonds falling below the specification limit of 20 grams-force. With the ribbon bonding process demonstrating a mean of 77 grams-force and a standard deviation of 30, the resulting sigma was 1.9. From standard normal tables we find that based on this data we could expect a probability of failure of approximately 2.87% or 1/35; a process capability that is a long ways away from a desired sigma of 3.72.¹⁵

First pass electrical testing experienced ribbon bond failure rates of approximately 2000 DPMO (defects per million opportunities). As a result, approximately 12% of the radar units tested required manual rework of faulty ribbon bonds. Final electric test, which is the final test

¹³ A ribbon bond failure results in either a short or open circuit during electrical testing.

¹⁴ Based on goodness-of-fit test (Shapiro-Wilk W Test) performed on data set, normality assumption is valid. Refer to (Owens, pp. 595-601) for further discussion on wire pull and normality assumptions.

¹⁵ A sigma of 3.72 provides a probability of failure of approximately 0.01% which meets the initial design specifications estimated failure rate of 1/10000.

before radar installation, produced a small but significant number of failures as well with failure rates of approximately 100 DPMO representing 1% of the radar units passing through test.

3.4.3 Production Bottleneck

With the radar unit production line now fully ramped up product was being released to the floor to meet daily requirements of 20+ units/day. However, with production output less than 15 units/per day there was clear indication a major system bottleneck existed (Goldratt, pp.139). Based on racks upon racks of WIP in the ribbon bond room, even to the untrained eye it was evident that the bottleneck lied in the ribbon bond process.

As stated in chapter 2 under ideal conditions, operating two shifts, the Palomar 3470-II can produce over 30 units per day. Even under the conditions in which the Palomar 3470-II experienced constant interruption due to ribbon failures, the bonder's capacity was greater than the then current production throughput of 15 units/day. So was the Palomar 3470-II actually the system bottleneck? By definition the answer is no, however through indirect means the Palomar 3470-II was the real cause of the bottleneck. The poor process capability of the Palomar 3470-II produced a downstream bottleneck in the form of rework.

Ribbon bonding rework is generated by three means: failures during bonding as described in section 3.4.1, failures during test as described in section 3.4.2, and self generated rework as a result of sample destructive pull tests.¹⁶ Figure 3.5 represents the ribbon bond process flow depicting the locations of the three types of rework. To ensure the original cause of failure is adequately addressed and to prevent repeat failures, rework is manually performed on the semi-automatic Westbond machines. Combining the large quantity of rework in the line and the manual nature of the rework process, the Westbond machines became the system bottleneck. Each radar unit required, on average, rework of approximately 30 ribbons. With each ribbon taking approximately 2 min/bond, for every unit an extra hour of touch labor is required on the Westbond alone. Additionally, not contributing to the bottleneck but adding to the amount of ribbon bonding process touch labor and thus production cost, to verify the quality of the manually reworked bonds each reworked bond must be non-destructively pull tested and then visually inspected.

¹⁶ As stated earlier, 4 ribbons were destructively pulled on every other radar unit. This large amount of sampling was required due to the high variability and resulting unproven reliability in the automated bonding process. As the process matured and confidence increased, the sample rate was readdressed.

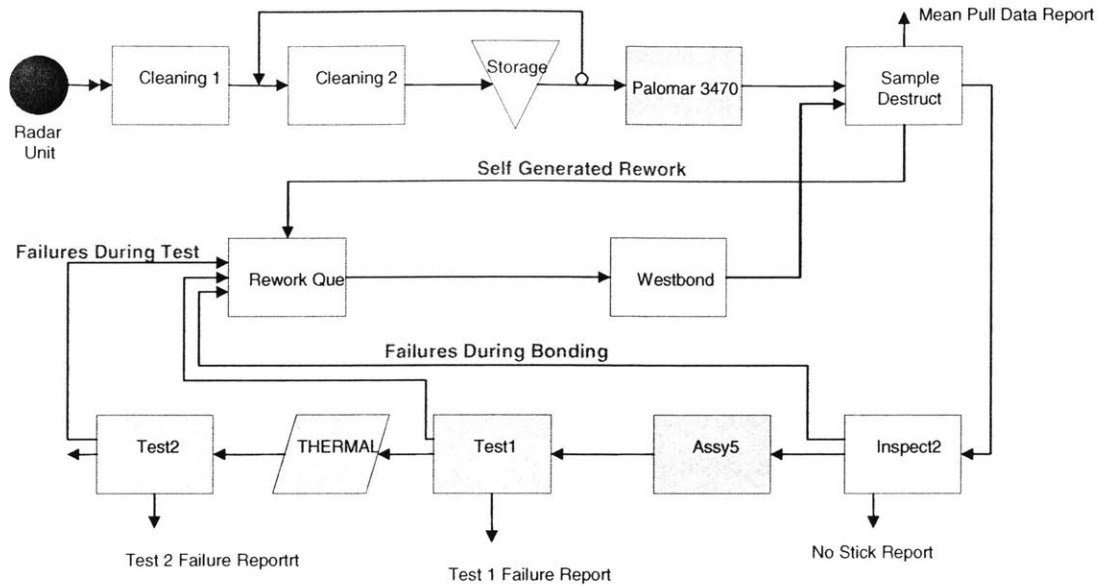


Figure 3.5 – Process Flow Diagram (w/ Rework)

3.4.4 *Attacking the Problem*

With every day that went by, because the radar delivery date remained fixed, as daily production rates were not met, the urgency for making rates became greater and greater. What was a production requirement of 20 units one day became 20+ units the next day and the likelihood of an on-time delivery became less and less a reality.

A feasible, short term solution to tackling the rate problem and shifting the bottleneck was to increase the capacity of the Westbond machines. In attempt to prevent making a bad situation worse, this was accomplished through purchasing of two new Westbond machines (for a total of 5) as well as implementing a third shift focused on eliminating the rework stockpile. Setting up the equipment as well as training new operators took time, thus any increase in rate seen by this solution was dampened by the continuing increase in urgency. Additionally, while this solution focused on temporarily reducing the growing stockpile, the real solution lied in eliminating the actual cause of the stockpile.

Eliminating the large amounts of rework by attacking the root cause, poor bond quality on the Palomar 3470-II, is the long term solution to the problem. Understanding the urgency of the problem, Raytheon established a team of subject matter experts whose only instructions were to solve the ribbon bonding problem. The team was made up of a wide array of disciplines from materials engineers to manufacturing engineers with over 20 years of ribbon/wire bonding experience. It is the collaborative work of this team that is responsible for the accomplishments highlighted throughout the remainder of this work.

3.5 *Summary*

Wire/ribbon bonding is an interconnect technology that has been successfully used in the microelectronic industry for over thirty years. It uses a combination of heat, force, and/or ultrasonic energy to form a metallurgical bond typically between high purity (99.999%) gold wire or ribbon and a high purity gold pad. Due to many unique design features on the radar unit, most significantly a large-scale bonding area, IDS Operations/Andover faced a new set of ribbon bonding challenges uncommon to the industry. These challenges resulted in low yields and thus increased levels of rework on the radar unit line. In response, a team of subject matter experts was assembled with the goal of improving process yields and rates. The efforts and successes of this team serve as a basis for the bulk of this work.

4 Data Management Systems

Compounding the technical difficulties IDS Operations/Andover faced with the ribbon bond process explained in the last chapter, one of the major hurdles to operating an efficient and quality “high-volume” manufacturing line has been the effective use of a data management system. Although systems are in place many examples of system inefficiencies and inaccuracies are present. This chapter focuses on the current data management systems and provides recommendations as well as begins to discuss an initiative taken to improve the ribbon bond process’ means of data collection and analysis.

4.1 *Designed for Low Volume*

The flow of product along the surface radar manufacturing line, which includes the ribbon bond process, is controlled by an Oracle based shop floor data management system (SFDM). This system was initially designed for use at another Raytheon facility and with the introduction of the “high-volume” surface radar line was brought in to replace manual production management systems. While the core of the system has high-volume capability, suboptimum configuration made it less conducive to efficient data management of a high-volume line.

The main purpose of SFDM is to manage product flow through the line. However, the system is also extensively used to collect non-conformance data.¹⁷ At each process step the operator logs the start and completion of each operation and if necessary also enters any non-conformances. The system effectively captures all of this information, although significant issues lie in the format in which data is collected. For example, after ribbon bonding of all 184 ribbons is performed a 100% inspection of each radar unit is performed. Any faulty ribbons are logged as a non-conformance, however the only method of recording descriptive fault location is in a text based comment field. On a low-volume manufacturing line this format of data entry is acceptable. On the other hand, in a high-volume environment in which large numbers of faults are entered each day this method is not only inefficient but more importantly severely inhibits data analysis.

In addition to the process flow and fault data that is collected by SFDM, the ribbon bond process produces significant amounts of destructive pull test data. The data is essential to proper monitoring of process capability and bond reliability. Since this data is very specific to only the ribbon bonding process and not initially seen as critical process flow information, the SFDM system was not configured to collect this data. To fulfill this need, an Excel based software

¹⁷ A non-conformance is written against a part in the event of a test or inspection failure or observed defect.

program was developed and continuously improved by the author throughout this work. With this program pull test data is entered, visual controls provide pass/fail user feedback, and basic control charts display process trends. This program is very user friendly, provides excellent real time data, and is a beginning to effective visual tool utilization. However, the tool has one major drawback. Given the high-volume rate of the line and the amount of data that is entered and analyzed on a daily basis, upkeep of a manual system such as this is not feasible.

4.2 *Redesign Required to Turn Data into Information*

As briefly mentioned above the biggest fault that exists in the current utilization of SFDM is the inability to obtain accurate and meaningful data output. In other words, the current system is only useful in producing data and not information. Defending the system, SFDM has this capability and presently is downloaded on a periodic basis to a large database from which any type of data analysis is achievable.¹⁸ Thus, the real issues lie in the way data is being collected.

In order to solve a quality or process problem such as the existing ribbon bond problem it is important to be able to process all available information. For every single radar unit that moves through the ribbon bonding process, multitudes of important data from machine faults to bond reliability is captured by the data management system. However, if data is not carefully and systematically recorded, especially at the point of manufacture or operation, it cannot be analyzed and put to use (Oakland, pp. 42). As pointed out in the example used in the previous section, ribbon bonding fault data is being collected in text formats. Because of this format without extensive manual intervention this data could never be turned into useful information. Due to the priority of needing to turn this data into information to solve the existing ribbon bond problem, throughout this work extensive manual work was done by the author to temporarily put all the fault data into a usable format to output critical information. Unfortunately, in order to devise a framework for long term problem solving and continuous improvement a data management system that requires labor intensive manual data extraction is not the solution.

4.3 *Potential for Improvements*

Even once the major technical problems are overcome, both the fault data as well as the pull test data is critical on a daily basis in the ribbon bonding room to understanding daily process capabilities and highlighting potential problems. Employees are intelligent individuals who are motivated by work that keeps them informed about how their efforts affect the outcome and gives

¹⁸ Most of the SFDM data is downloaded to the database on a nightly basis, if not more frequently.

them power and responsibility to reach their goals (Greif, pp. xvii). Thus, the need to improve the methods of data collection and management is very evident. Therefore, in addition to maximizing the use of the current data management system to solve the problem at hand (whether this meant writing parse programs that extracted text data or continuously upgrading the Excel spreadsheet to utilize visual tools), working toward improving the current system became a high priority of this work.

As a result of successes the temporary methods of utilizing visual tools produced in solving the ribbon bonding problems, two initiatives driving this long term data management restructuring have gained strong support. One initiative involves restructuring the format in which fault data is taken. The initiative involves development of an electronic interface that allows the user to pick on the screen the specific location of the fault and using drop down menus select the fault type. This would replace manual entry of fault data into text fields with electronic capturing of data that can immediately be uploaded into a database. Because the data would now be in a usable format, any form of output information such as fault DPU determination to fault location mapping could be easily performed. Unfortunately, a major restructuring of the SFDM system requires extensive work and resources and due to the time constraints of this work, only proposals were developed. As of December 2003, a Raytheon six sigma team was formed with the goal of restructuring the methods in which non-conformance data is collected over the entire surface radar line.

A second initiative involves replacing the current Excel program used to collect pull test data with a new system. In order to effectively promote lasting continuous improvement efforts through daily process monitoring an automated system is needed. This new system, which was implemented by the author in November 2003, has the capability to both automatically collect pull test results and produce “real-time” process information in the form of visual aids and SPC charts. Chapter 7 provides details of this system and its importance in controlling and promoting continuous improvement in the ribbon bonding process.

4.4 Summary

An effective data management system not only captures data but transforms this data into information. To successfully meet the goal of eliminating the ribbon bond yield and rate problems this data transformation was essential. Unfortunately, due to inefficiencies and inaccuracies in the way data is collected and managed, transformation was inhibited by the current data management system. To overcome this, throughout this work, both temporary and

long term initiatives were implemented which led to improved data transformation and ultimately helped drive a solution.

5 Bringing Forth a Solution

As mentioned in Chapter 3, a team of subject matter experts was formed to solve the ribbon bond problem. While this was a step in the right direction, the real challenge was incorporating a systematic problem solving approach centralized around understanding the state of the process as experimentation is performed and process changes are implemented. This chapter focuses on how use of a methodical approach led to the elimination of the ribbon bond problem. Furthermore, it delves into how, by overcoming the ineffectiveness of the data collection and management system, utilization of visual tools became the critical element in determining the root causes, measuring process capabilities, and driving decisions. Additionally, embedded in discussion of the problem solving approach, is a description of the two major technical initiatives that led to the overall ribbon bond process solution and significant cost savings on the surface radar line.

5.1 Understanding a Multivariate Problem

Observing actual production floor data of ribbon bond faults/unit and destructive pull test bond force for a given day (Figure 5.1a and 5.1b) it is evident that the process represented a potentially out-of-control situation.

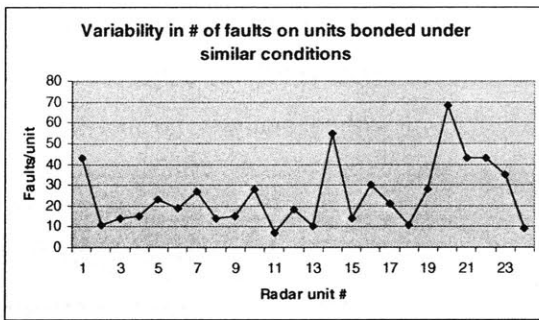


Figure 5.1a – Bond Fault Variability

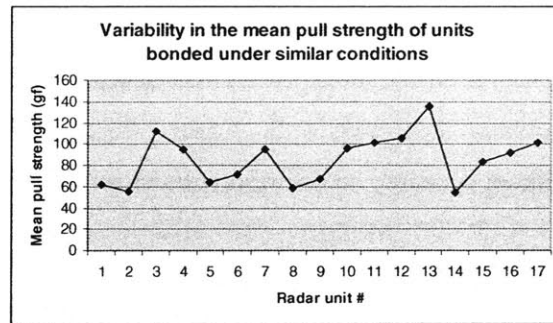


Figure 5.1b – Bond Strength Variability

The major contributor to this out-of-control process was the multivariate nature of the process. As evident from the cause and effect diagram detailed in Figure 5.2 there are numerous variables that control the ribbon bonding process (Eisenberg and Jensen, pp.66). As with all processes these variables can be characterized as either controllable or uncontrollable factors. Thus, the first and probably most difficult step was overcoming this multivariate problem by differentiating between the noise and controllable factors in the system.

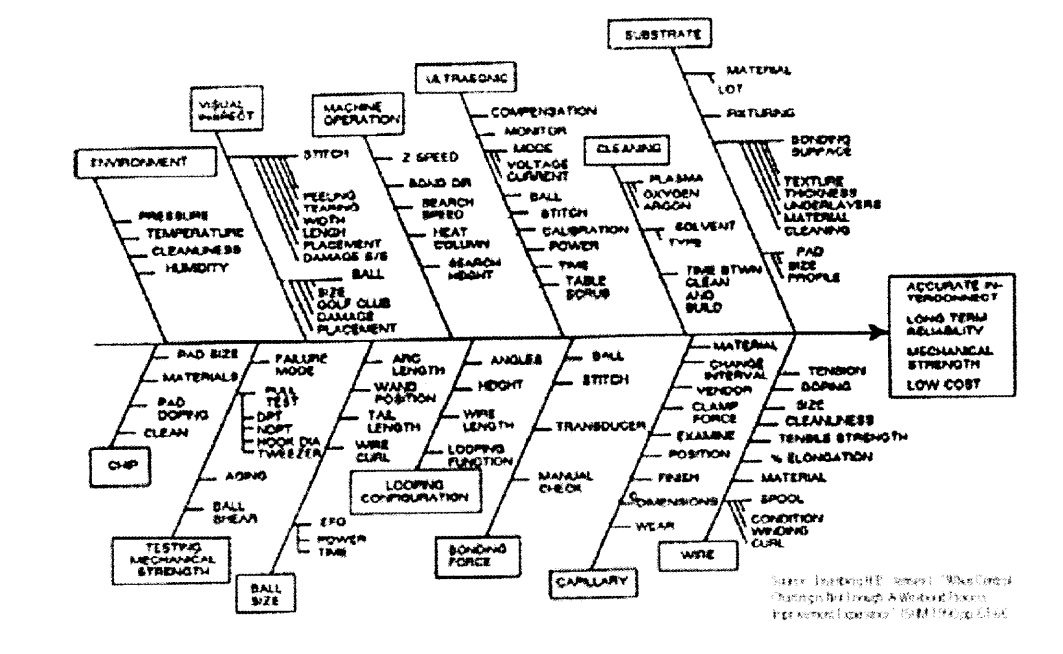


Figure 5.2 – Ribbon Bonding Cause and Effect Diagram

5.2 Approaching the Problem

The ribbon bond team was made up a number of very knowledgeable subject matter experts who understood the problem and the major factors that drove the process yet struggled in moving forward towards a solution. Missing was a systematic approach to solving a process control problem, an approach that incorporated the run rules essential in solving a process control problem: no process without data collection, no data collection without analysis, no analysis without decision, no decision without action (Oakland, pp.42).

5.2.1 Defining a Methodology

With both technical and cultural difficulties to overcome only a well-organized approach would bring success; an approach incorporating a methodology that not only overcame the root causes and technical factors but also drove decision and process changes. A real need for action existed and unless the approach included both engineering and managerial aspects the solution would not be achieved in the time frame needed. The approach the team utilized was one that stepped through controlling, improving capability, and optimizing the process simultaneously through a multi-feedback process as defined in Figure 5.3 (Eisenberg and Jensen, pp.62).¹⁹

¹⁹ In defining this approach Eisenberg and Jensen utilized a four process approach that included process definition. In our situation the first step of process definition was already completed and given the scope constraints of this work was not revisited.

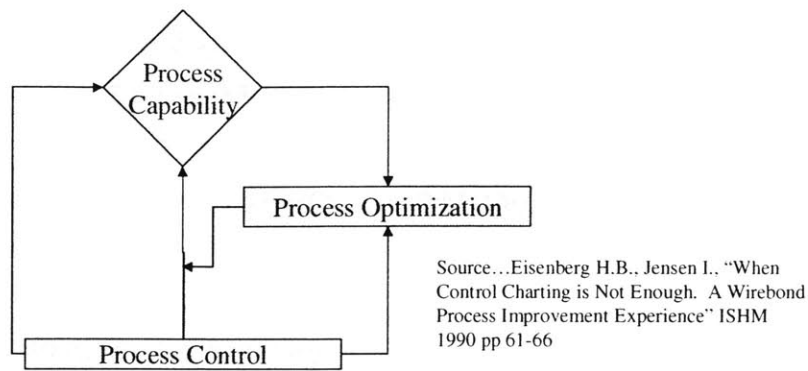


Figure 5.3 – Process Improvement Approach

Embedded in the three steps of the approach, control, capability, and optimization, was the use of various engineering tools and methods. Development of metrics and use of visual tools helped to both define and measure process capability. Utilization of root cause analysis led to an understanding of the controllable and uncontrollable factors necessary to determine improvement steps required to bring the process into control. Once process improvement step changes were made a design of experiments was required to optimize the process parameters. Lastly, statistical tools such as statistical process control serve to continuously monitor process performance once the process was in control.

As important as the presence of engineering tools and methods were in the approach, management factors played a big part in the methodology as well. Without the proper managerial decision making and action stemming from the analysis and tools developed within the three steps there would have been no means to move forward from one step to the next. Using Figure 5.3 as a model of the approach, the managerial aspects of the approach can be found in the flow arrows serving to drive the improvement process forward.

5.3 Visual Tools - Data Transformation and Decision Lead to Action

In revisiting the four elements of the run rules essential in solving a process control problem: data collection, analysis, decision, action, one can conclude that each element is equally important as the next and elimination of any one would prevent achieving a solution. The systematic approach modeled in Figure 5.3 and detailed above provided a systematic methodology to solving the problem, but more important than the methodology and the specific tools it utilized, is the one critical element embedded in the approach that brought forth and tied the four essential run rules together. This critical element was visual tools and their role in data collection, analysis, and decision which ultimately led to action.

Visual tools became the backbone to the entire problem solving process as they played a critical role in each one of the four elements. By providing user friendly interfaces they promoted efficient and effective data collection. Their role in turning data into information was essential in process analysis leading to needed buy-in and ultimately decision making. Lastly, by building momentum and providing the necessary feedback visual tools were critical in turning decisions into action.

5.3.1 Data Collection

While data analysis is arguably the most notable role visual tools can play in a problem solving process, the use of these tools at the analysis level inherently drives requirements at the data collection level. If data is not carefully and systematically recorded at the time of generation i.e. the right data in the right format, then it can not be properly put to use.

Before the implementation of visual tools in solving the ribbon bonding problem this was exactly the case. As mentioned previously in this work, ribbon bond fault data was being collected in a format (text based comment fields) that required an individual to manually extract the data and reenter it back into a spreadsheet to perform any data analysis. In the case of ribbon bond strength data, while data was collected in a way that allowed for analysis with minor manual intervention, the proper data required to analyze process capabilities and trends was not being collected. Development of visual tools to transform data into information highlighted an urgent need for a change in how and what ribbon bonding data was being collected.

In order to meet the data collection needs required by visual tools in the analysis phase, many changes to the way data is collected have been made and many more improvements are in the works. Operators collecting fault data (which at the conclusion of this work due to the current data management system constraints is still being collected in comment fields) have been trained to enter the data in a standardized format allowing for easier extraction. A new current initiative will hopefully eliminate the text fields altogether and provide standardized pick lists. Bond pull data, originally manually entered into a spreadsheet, through use of a user friendly visual interface is now collected automatically into a database where data analysis using various visual tools can be performed at the click of a button. In addition to how the bond pull data is collected, using visual tools to analyze bond pull data highlighted the need to not only collect the strength of bonds but also the failure modes. Transforming this new piece of data into information at the analysis phase assisted in root cause analysis at the component level.

Utilizing visual tools became critical in shaping the first step in the approach to solving the ribbon bond process control problem, data collection. The use of visual tools shifted the old

paradigm of collecting data for the sake of collection to a new thinking of collecting because of a need for information.

5.3.2 Analysis

With data collection aligned to capture the right data in the right format, analysis through use of visual tools drives the transformation of data into useful information. In solving the ribbon bonding problem a variety of different forms of visual tools were developed by the author. These tools ranged from simple Pareto charting used to prioritize the problem areas, to bar graphs showing daily trends, to user interfaces flooded with various visual controls that provided real time feedback to operators. While the formats of these tools were unique to one another they all served the same purpose of making sense of what was previously construed as just “data”. Examples of the different tools developed and used during the course of this work are detailed below.

One of the most effective, yet most difficult to develop and maintain visual tool, given the current data management system and the format in which fault data is collected, was the fault location map (Figure 5.4). This tool compiles bond failure data obtained over a period of time at any process step and graphically displays their physical location. Utilization of this tool helped bring forward underlying issues and helped to drive root cause analysis down to the component level. For example, Figure 5.4 displays the number of faults per bond site discovered at inspection over the period of a week on one of the radar unit’s channels. Analysis of the fault map showed that a significant number of faults were occurring in the lower right corner of the circuit. As it turns out, this area represents one specific component. Highlighting this effect helped justify a shift to a second source supplier and improved the rigidity of the component design leading to a decrease in faults in this area.

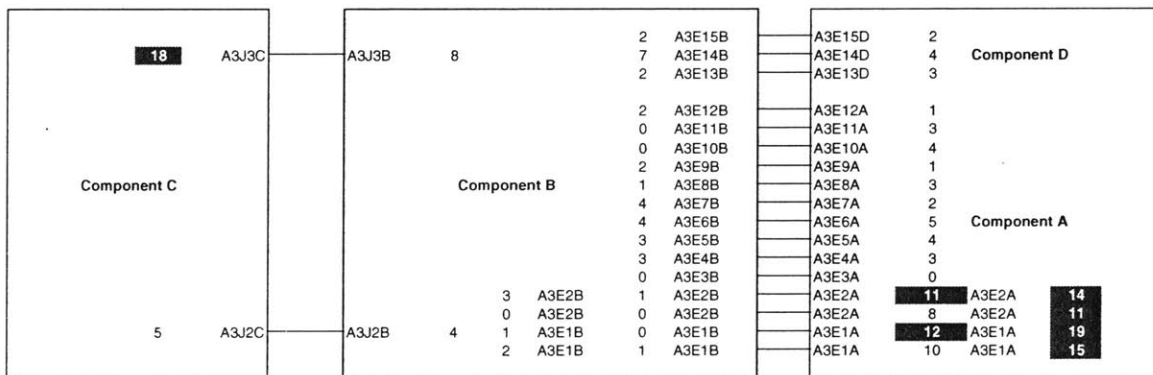


Figure 5.4 – Fault Location Map

Of the three steps in our problem solving approach, arguably the most important was improving process capability. As part of the effort to achieve improved process capability a number of systematic trial and error process experiments were performed. In order to capture the effect of these process changes and determine the “best” process, a simple but extremely critical visual tool was used. The tool as shown in Figure 5.5 was a bar graph that displayed the daily faults/unit occurring during automated ribbon bonding. The tool became effective in two ways. First, it allowed the team to track the process capability resulting from process changes. More importantly, it led to generation of a metric that became an important judge of process capability that surprisingly was never previously measured, faults/unit. This metric became a standard reporting metric that drove decision making internally to our team, but also a metric that has been used to report process capability to key stakeholders from the plant manager to the customer.

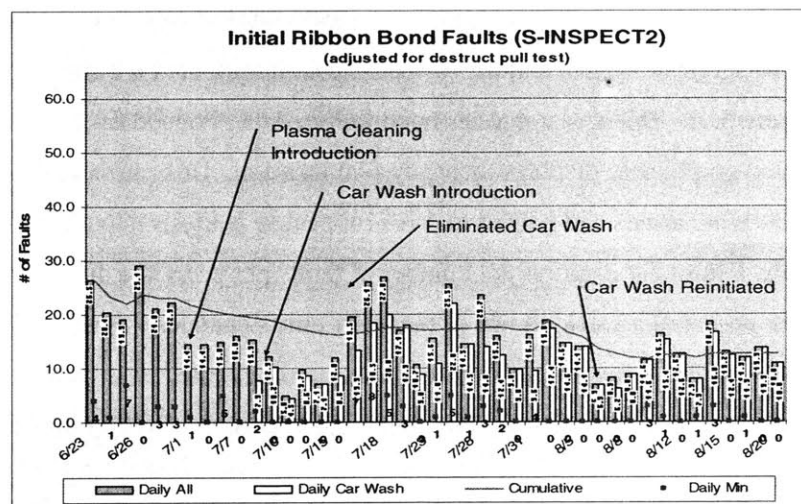


Figure 5.5 – Daily Fault/unit Chart

In addition to measuring the number of faults per unit, process capability is also determined by destructive pull test measurements. For each set of ribbons that are pulled, bond strength data was recorded by the pull test operator. In order to provide real time process feedback to the operators, a number of visual tools were implemented. Combining visual controls and statistical process control, a user interface provided the operator with color coded user friendly signals that informed the operator whether the current measurement was within control limits. One layer behind this initial interface was another visual tool that provided Xbar/s and attribute charts utilized by the ribbon bond engineers to help monitor trends in process capability. Figure 5.6a and 5.6b provide screen shots of these tools. While these tools were well embraced

on the floor one of the major drawbacks was the amount of time required to maintain the tools. As a solution to this problem, during the course of this work, an automated system was developed and implemented to automatically capture and process this data. Chapter 7 provides a detailed look into this new system.

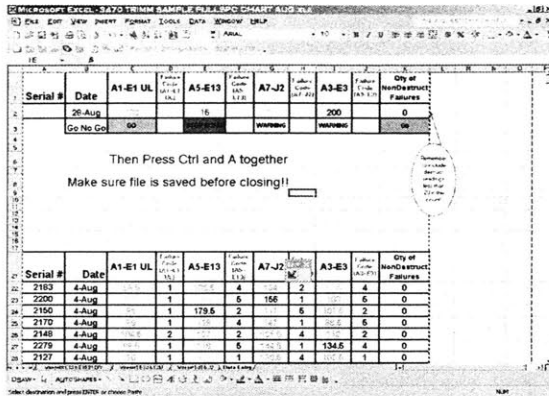


Figure 5.6a – Bond Pull Interface

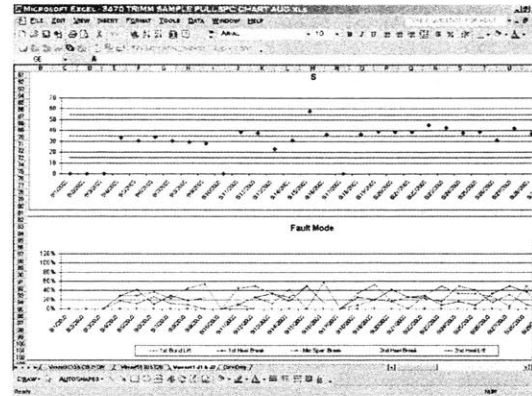


Figure 5.6b – Bond Pull SPC

5.3.3 Decision

By providing a new set of indisputable information in a clear, concise format visual tools are essential in moving forward the problem solving process through decision making. In solving the ribbon bond problem the team’s approach was completely reliant on the use of visual tools. No decision was made and no process step was changed unless the information given by the various tools demonstrated that it was the right decision.

In addition to internal team decisions, visual tools were critical in driving external decision making. For example, during a critical phase of process improvement the team internally determined that a major process change needed to be made regarding how the product was cleaned prior to ribbon bonding. Internally, using visual tools, the team had determined that this was the right approach to take. However, due to concerns that this new process might cause damage to other components and would lead to other forms of rework, the team received a lot of pushback from engineering. Relying heavily on presenting the right information in the right format through use of visual tools to the external engineering decision makers, the team was able to prove that the benefits of the process change outweighed the risks and obtained the necessary buy-in from engineering to move forward with the change.

However, utilizing information in the form of visual tools to make decisions is not as easy as simply throwing a bunch of charts together. A visual tool is useful only if it answers a pertinent question. In the scenario in which the team needed to obtain engineering buy-in

described above, the team learned this lesson first hand. In the first meeting between the team and engineering, using visual tools the team presented several pieces of information that they felt were needed to convince engineering that this was the right decision. However, the questions the tools answered were not the questions engineering was asking. As it turns out the right information was in the data but was transformed, from engineering's perspective, into the "wrong" information. Now knowing what questions needed to be answered the data was retransformed and visual tools containing the "right" information was presented leading to the necessary engineering buy-in.

5.3.4 Action

The last step in solving a process control problem is turning the decisions made into action. Once again the driving force behind turning decisions into action was utilization of visual tools. Many times when decisions are made unless there is constant momentum pushing these decisions forward no action is ever taken. Visual tools provide this momentum in two ways. First, they have the capability to provide sound information that leads to not only decisions but to the first action steps. For example, the team recommended a second major ribbon bonding process change which required fabrication of bonding fixtures that added heat to the radar units. Each of these fixtures cost over \$20,000 thus funding was required to turn the decision into action. Presenting the right information to the program manager that turned data from experiments into predicted future process capability led to project funding and fabrication of four fixtures. Secondly, once action is taken visual tools provide the necessary feedback that maintains the momentum to move forward with the action or, if necessary, provide recommendations for course changes. Without the appropriate feedback many times change initiatives fizzle out, because unless there is visual proof that this is the right action the natural tendency is to revert back to the way things were.

5.4 Two-Phase Revolutionary Change

From a detailed analysis and understanding of the cause and effect diagram of Figure 5.2 and through extensive background research and internal and external benchmarking, the ribbon bond team determined that there were two key areas of focus that could potentially lead to big hit wins. These two areas were cleaning and heating. The first step in a sound quality improvement program is to get the process in control and the second step is to shift the process mean to an improved value (Vining, pp. 216). The two areas fit well with this line of thinking. The team believed that the majority of the process noise was driven by contamination issues, thus a

heightened awareness of these issues leading to an improved cleaning process would bring the process under control. Secondly, experimentation and benchmarking studies across the board showed evidence that adding heat to the work stage would drastically improve process capability by doubling the bond strength.

Understanding the potential for improvements these two areas could bring, through use of the systematic approach described earlier, the team successfully incorporated a two phased revolutionary process improvement effort. The phases of process improvement are defined as revolutionary because they led to major step changes in the ribbon bonding process. At the core of each phase was the utilization of the methodologies and visual tools described above. Figure 5.7 is a diagram summarizing the two phases of improvement.

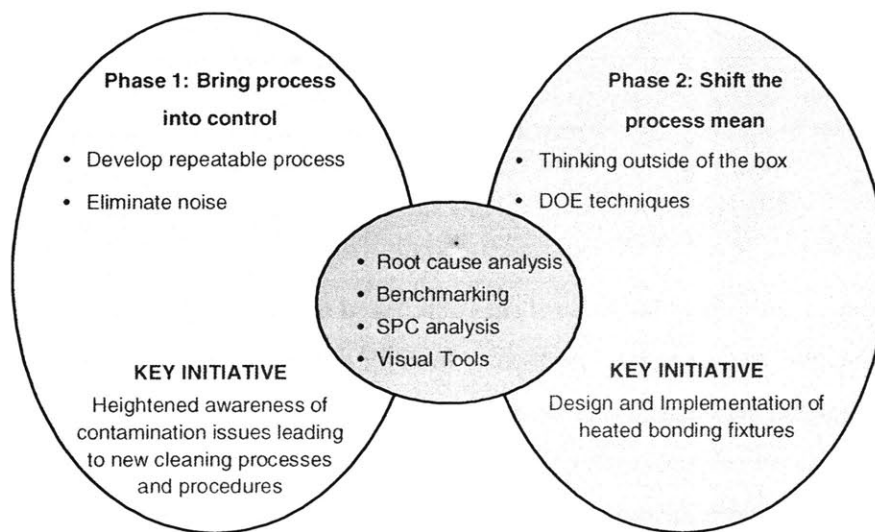


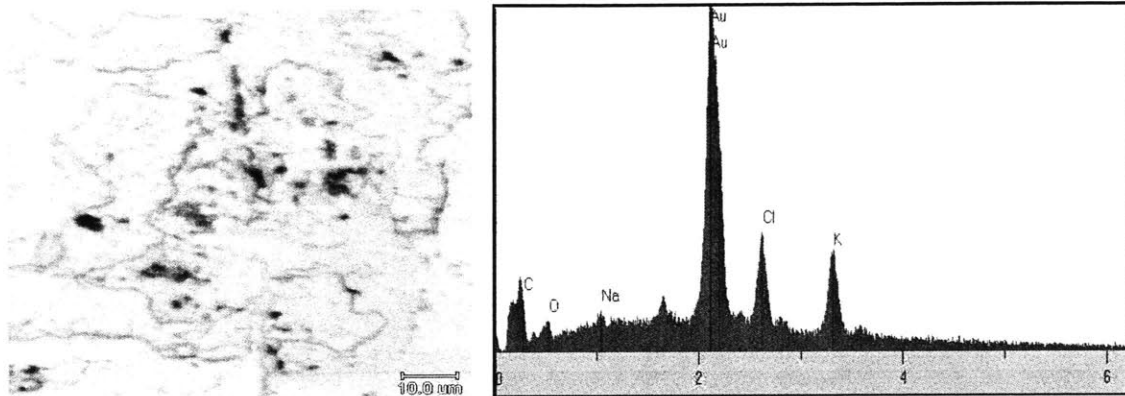
Figure 5.7 – Two-Phased Revolutionary Process Improvement

5.4.1 *Cleaning*

The first phase was centered on a heightened awareness of contamination at the bond sites leading to improved cleaning processes and procedures. Research has shown that contaminants on bonds degrade both the bondability and reliability of bond pads (Harman, pp. 181). Nevertheless, on the radar unit line maintaining cleanliness was not viewed as a top priority. The bond room was isolated from the rest of the line with the idea of maintaining a cleaner environment.²⁰ Ironically, in many instances this room visually appeared dirtier than the rest of the line. Procedurally, finger cots were required at all operations but in practice used

²⁰ The room was not intended to be a class specified clean room. Defined as “hospital grade” equipped with a hepa filter and temperature and humidity controlled, it was intended to be a cleaner room than the outside area.

sporadically. As a result, prior to bonding many instances of contamination were found ranging from organic tape residue to finger oils. Figure 5.8 represents results a sample of SEM²¹ analysis performed on bond sites experiencing no-sticks at bonding. This analysis was performed as part of a root cause analysis to determine why bonds were, in what appeared to be a random fashion, not sticking during bonding.



Contamination in failed bond footprint contains Na, Cl, K suggesting finger oils.

Figure 5.8 – SEM Analysis Identifying Contamination

Continued analysis of failed bond sites concluded that contamination was a critical factor in both the yield and process control problems. In order to maintain a consistent level of cleanliness at bonding and therefore bring the process closer to being in control it was determined that a cleaning step was essential prior to ribbon bonding. Numerous cleaning methods were initially experimented with including burnishing,²² alcohol swabbing, and vericlean spray. However, analysis of process capability metrics produced erratic results. Benchmarking internally with Raytheon’s Advanced Product Center revealed successful ribbon bond efforts were made after cleaning the product in a plasma chamber.²³ Experimentation with radar units cleaned in a plasma chamber produced improved results, yet inconsistencies still remained. The final hurdle was overcome when experimentation revealed cleaning radars units in a high-pressure alcohol wash (typically used in circuit card assembly and dubbed the “car wash”) produced a drastically improved and consistent process. By following the alcohol wash with plasma cleaning, a 60% reduction in bond failures was achieved. (Table 5.1 provides a summary of various cleaning method results, CCA represents high-pressure alcohol wash).

²¹ SEM (Scanning Electron Microscopy) produces images by scanning a focused electron beam across the surface of a specimen.

²² Burnishing actually worsened the situation as it embedded the contamination into the bond sites.

²³ Plasma cleaning is a method of cleaning that uses a high energy gas stream to oxidize organic contamination and mechanically scrub particle contamination.

Average Values	# OF SAMPLES**	DESTRUCT PULL TEST RESULTS			# OF SIGMA FROM 20gf	DESTRUCT FAILURES	NON DESTRUCT FAILURES	INSPECTION RESULTS	
		MEAN	STD. DEV.					TOTAL	CORRECTED TOTAL ***
BURNISH	7	82.0	26.0	2.38	0	0	28.9	16.0	
PLASMA 15 - ALCOHOL	32	94.2	29.7	2.49	0	0	19.8	9.4	
CCA - PLASMA 200W/5 min, ~4 hrs	124	105.8	31.4	2.73	2	2	11.0	5.5	
BURNISH - CCA w/o rf - PLASMA	21	108.6	32.6	2.41	0	0	14.5	8.4	
CCA w/o rf - PLASMA	55	110.8	38.1	2.38	1	2	14.3	9.1	

* Removed at PT represents # of bonds missing as a result of destruct pull test
** E1/E2 effect represents bonds missing as a result of operator skipping bonds due to missing lower bonds (i.e. if LL bond is missed then operator skips UL,LR, and UR; if LR bond is missed then operator skips UR bond)
*** Corrected Total = Total failures at S-INSPECT2 minus removed @PT minus E1/E2 effect
**** Represents the # of samples completed S-INSPECT2

Table 5.1 – Summary of Experimental Cleaning Results

As an additional benefit to the Integrated Air Defense Center, these new cleaning methods were batch processes on currently held underutilized assets with capacity available, and thus required no additional capital investment. Figure 5.9 is a picture of the Aquastorm high-pressure alcohol wash and Figure 5.10 is a picture of the Anatech plasma cleaner currently used to clean radar units.

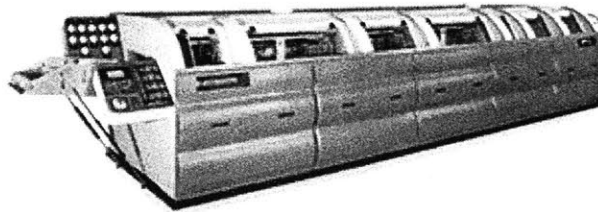


Figure 5.9 – Aquastorm 200 Cleaner

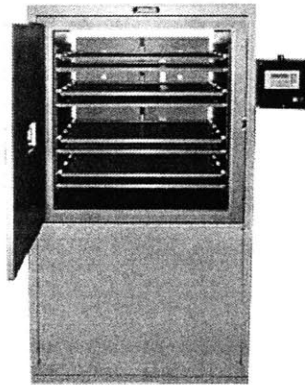


Figure 5.10 – Anatech Plasma Chamber

Combining this improved cleaning process with a heightened awareness of the need for a process clear of contamination resulted in a more consistent use of finger cots and SPC charting showed a process very close to being in control. Nevertheless, test failures were still occurring, indicating a need for a shift in the process mean.

5.4.2 Heating

Although a revolutionary improvement was made through implementation of an improved cleaning process, room for improvement still remained. On average, each radar unit still required rework of approximately 10 bonds (overall radar unit yield was now ~13%) and additional rework was also still being seen from test failures. With an ultimate goal of zero failures on the automated bonder and <1/10000 at pull test, additional process improvement was required. Extensive benchmarking of industry practices yielded improved success when bonding was performed on a heated work stage. Due to the uniqueness of the radar unit geometry and locality of bonds sites to heat sensitive rf components the idea of adding heat was greeted with large amounts of pushback from both engineering and manufacturing. With the confidence that this was the only means of reaching the required levels of bond yield and quality the team challenged the skepticism and moved forward in proving the importance of heat. Using a pre-existing smaller heated stage a controlled experiment was performed on non production parts at 25°C, 85°C, and 125°C. These results showed a correlation between the strength of the bonds and an increase in heated stage temperature.²⁴ Table 5.2 summarizes the results of this experiment.

Test of Temperature Effects on Ribbon Bond

	AMBIENT	85 degrees C	125 degrees C
Mean:	116.2	148.9	139.7
Std Dev:	35.8	35.2	41.7
<i># of Sigma from 20 gf</i>	2.7	3.7	2.9
<i>Missing Bonds:</i>	5	0	4
<i>1st Bond Lifts:</i>	3	1	0
<i>2nd Bond Lifts:</i>	33	35	14
<i>1st Heel Breaks:</i>	5	16	35
<i>2nd Heel Breaks:</i>	10	4	3

Table 5.2 – Summary of Temperature Effects

Based on the result of this experiment a follow-on experiment was designed and performed on production components to help understand the effects of different Palomar 3470-II parameter settings when bonding at 125°C. Table 5.3 summarizes the results of this experiment.

²⁴ Two factors play a part in determining strength of the bond, the quantitative pull strength force measurement and the means by which the bond failed during pull test. Based on consideration of these two factors 125°C was determined to be the optimal bonding temperature.

Factor Row #	A Force	B Time	C Power	Ribbon Pull Ste					Y bar	S
				Y1	Y2	Y3	Y4	Y5		
1	104	500	60	190.5	171.5	166.5	152.5	237.5	183.7	33.0106
2	104	500	90	62.0	127.0	124.0	173.5	140.5	125.4	40.5145
3	104	700	60	224.5	234.5	216.0	216.5	220.5	222.4	7.586172
4	104	700	90	160.5	178.0	182.5	163.0	131.0	163	20.22066
5	126	500	60	239.5	221.5	193.0	202.5	228.5	217	19.00658
6	126	500	90	101.0	126.5	134.0	121.5	142.0	125	15.49597
7	126	700	60	209.0	160.5	195.0	165.5	167.0	179.4	21.3524
8	126	700	90	115.5	71.5	106.0	91.5	159.5	108.8	32.83976

Table 5.3 – Effect of Bond Parameters at 125°C

Presentation of the results of these two experiments provided momentum for pursuing development (funding, design, and manufacture) of four heated stages designed to provide localized heat to the bonding sites. Figure 5.11 is a picture of a completed heated stage installed on the Palomar 3470-II. An infrared scan of a radar unit heated to 125°C (Figure 5.12) was used to prove that the temperature sensitive rf components would not be exposed to temperatures greater than specifications.

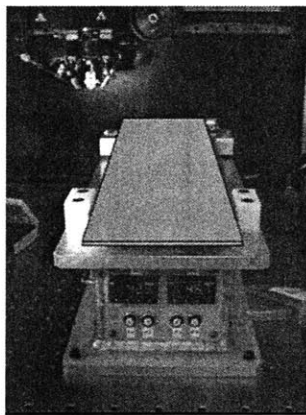


Figure 5.11 – Heated Stage

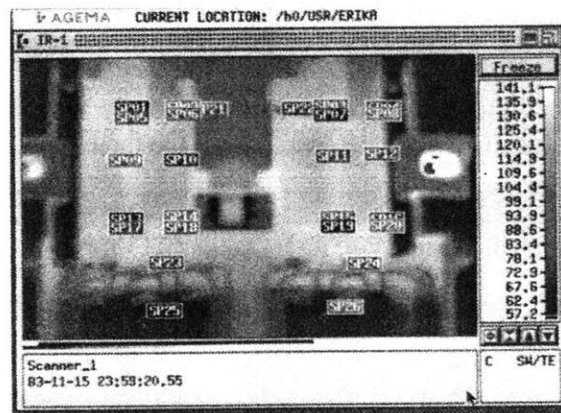


Figure 5.12 – Infrared Analysis of 125°C Radar Unit

Initial implementation of the heated stages on production parts provided exceptional results. The first production unit bonded at 125°C had zero no-sticks and pull test results indicated a 65% increase in bond strength and two times the process capability (number of sigma from failure). Bond parameters for this unit were set based on previous experience. However, as Table 5.3 shows, bonder parameters have a significant effect on bond strength. Thus, in order to obtain the maximum benefit of bonding with heat and achieve the maximum shift in process mean, bonding parameters needed to be optimized. Chapter 6 provides details of how parameter optimization was achieved through use of a design of experiments (DOE). Optimization provided a further increase in the process mean as post-optimization bond strength levels represented an increase of 83% from those seen before the introduction of heat.

5.5 Cost Savings

Implementation of both new cleaning processes and the introduction of heat during bonding have resulted in significant ribbon bonding process improvement. Major improvements in initial bonding yield have been experienced as well as increased yields at test due to stronger bonds. Table 5.4 summarizes the improvements made.

BEFORE	AFTER
☐ Cycle Time – 23 days	☐ Cycle Time – 1.9 days
☐ 27 faults/ unit (85% first pass yield)	☐ 2.4 faults/ unit (99.1% first pass yield)
☐ Mean pull strength 77gf	☐ Mean pull strength 191gf
☐ 1.7 sigma from mil-std failure	☐ 4.5 sigma from mil-std failure
☐ 100% units requiring rework	☐ 50% units requiring rework
☐ 2000 DPMO - 1 st pass electrical test	☐ 188 DPMO - 1 st pass electrical test
☐ 100 DPMO - final electrical test	☐ 0 DPMO – final electrical test

Table 5.4 – Summary of Process Improvements

These improvements have led to measurable decreases in the three types of rework previously seen, initial bond fail rework, rework of destruct pull test bonds,²⁵ and rework of bonds failing at test. This reduction in rework has resulted in direct labor and support cost avoidance savings of \$688K on the first radar and \$1.98M on the second radar. More importantly, these ribbon bond process improvements will lead to lower production costs on all future radars.

²⁵ As a result of an increase in process capability, the destruct pull test sampling requirements were decreased from four bonds on every other radar unit to six bonds every shift.

6 A Case for a DOE

With both the cleaning and heating process improvement efforts in place and fully implemented, the next step in maximizing the potential improvements was process optimization. Due to the multivariate nature of the ribbon bonding process, a statistically efficient and economical method of performing optimization was through a designed experiment (Montgomery, pp.4). This chapter, written as a case study, provides an example of how the successful design and execution of a design of experiments (DOE) led to the optimization of the ribbon bonding process parameters.

6.1 The Need for a Design of Experiments

In automated wire bonding many separate factors determine the strength of the bond and the mode of failure (Sheaffer and Levine, pp. 321). Determining which variables are really critical to the process and what levels these variables should be set at is a challenge that must be overcome to optimize the process and allow it to be insensitive to other uncontrollable noise factors (Eisenberg and Jensen, pp. 62). The advantage of using a design of experiments is that it allows one to estimate the effects of all variables independently and simultaneously test multiple output responses. Since the experiment was to be done on high-cost production parts that may have to be scrapped, it was important to test as many factors in as few experimental runs as possible.

6.1.1 The First DOE and Parameter Settings

During the spring of 2003, with ramp up of the radar unit in progress, initial setup of the Palomar 3470-II automatic ribbon bonding machine and process began. This involved establishment of optimized parameter settings, determination of process capability, and development of a process control plan. Because of its efficiency in developing a new process a design of experiments was used to determine the optimal parameter settings. However, after two design iterations the team conceded defeat. Wide swings in output responses were seen and showed no statistically significant correlation to any of the design parameters. It was concluded that the uncontrollable noise variables were too significant, and until this noise could be eliminated and the process matured optimal parameters could not be established. Nevertheless, with the line up and running, parameters needed to be set. Using these DOE results as an initial guide, through trial and error parameters were eventually established.

Introduction of new cleaning and heating processes in the fall of 2003, resulting from process improvement efforts, brought a change in the existing bonding variables. Bonding

surfaces were now much cleaner and the bonding temperature was increased from 25°C to 125°C. These changes inevitably redefined the bonding window and as a result dictated a need to establish new bonding parameters.

6.2 *Designing the Experiment*

With the goal being to determine the optimal bonding parameter settings of each of the four different types of radar unit components²⁶ an experimental design was required that 1) minimized the utilization of a machine currently being used for full production, and 2) minimized the waste of production parts. Typical with most design experiments, a full understanding of the characteristics of all parameters was unknown. Thus, the team established initial design guidelines with the understanding that a sequential approach would be taken, that is a design that would develop and change as the team learned more (Montgomery, pp. 7).

6.2.1 *Variable Selection*

At the time of the initial experiment design over 2000 radar units had been bonded on the Palomar 3470-II. Thus a relatively good understanding of which parameters had the most significant effect on the process was known. In order to minimize the size of the design and thus the number of runs required the three most significant parameters were selected. These parameters were bond force, bond time,²⁷ and ultrasonic power. Each of these parameters represented actual machine settings and thus could be carefully controlled both during the experiment and in production. Other parameters highly considered but not selected were fixture temperature and tool wear. Fixture temperature was not selected as an independent variable because benchmarking data and prior experiments proved “hotter is better”. A constant temperature of 125°C (the max allowable by the components) was used throughout the experiment. Tool wear was not selected as an independent variable due to experiment time constraints.

The response variable used was bond pull strength. Parameter optimization was to be determined by maximizing the mean pull strength and minimizing the standard deviation of the replications. Additionally, although not incorporated into the model, a subjective look at failure mode also played a part in determination of optimal settings.

²⁶ For the purpose of this exercise we will define the four components as component A, B, C, and D.

²⁷ Bond time represents the length of time ultrasonic energy is applied.

6.2.2 Choosing a Design

One of the most difficult tasks in development of the experiment was assigning values to the independent variables. With each of these factors being continuous and the goal to obtain quantitative parameter settings the levels were also chosen to be quantitative. Based on a smaller scale DOE performed prior to this there was evidence that the parameters may not have a linear relationship. Thus, to better predict the true shape of the response surface a three level design was chosen. The next step was determining the range of the variables. A large working range was selected to ensure the maximum point in the response surface was captured; and in order to maintain simplicity in the design the same levels were chosen for each of the four components. The resulting design was a 3^k ($k=3$) design. A full factorial design of this type requires 27 runs. Given the time and material constraints a half factorial design was chosen consisting of 13 runs which include one center point. A validation run performed after optimal settings were obtained made up the 14th run.

The final step was determining the number of replications required. The number of replications was chosen to be different for each of the four components. Since the four components differ in the number of bond sites available this was necessary given the amount of material available for the experiment. Ten replications were chosen for component A, five for B, three for C, and two for D. Given the variability still existent in the process, the preferred number of replications is at least five for each component but like the reality of many experiments both time and cost were substantial driving factors. Figure 6.1 represents the design for component B.

Factor Row #	A Force	B Time	C Power	MEAN (gf)				
				Y1	Y2	Y3	Y4	Y5
1	102	300	70					
2	102	700	70					
3	134	300	70					
4	134	700	70					
5	102	500	60					
6	102	500	80					
7	134	500	60					
8	134	500	80					
9	118	300	60					
10	118	300	80					
11	118	700	60					
12	118	700	80					
13	118	500	70					

Figure 6.1 – Component B Design

6.3 Setting up the Hardware

In normal production bonding of radar units, four different types of bonds exist. In each of these bond types the ribbon is bonded across two different components, i.e the first bond is placed on component A and the second bond on component B. The goal was to optimize the bonding parameters of each component. If experimental bonding duplicated the production

layout of bonding between two different components the effects of one component would potentially contaminate the results of the other. For example, if the experiment was designed to measure the strength of bonds on component A and the bond on component B fails first then the actual strength of component A's bond could not be measured. Thus, it was determined that unlike production bonding, all experimental bonding would be between identical components lined up toe to toe.

6.4 Optimization Results

Formal analysis of the experimental results was done using multiple regression. Optimal parameters were determined by optimization of the regression equations (maximizing mean and minimizing standard deviation).²⁸ A different regression equation, and thus a different set of parameters, was obtained for each of the four components. Figure 6.2 is an example of the regression output for component B. To verify the accuracy of the optimization results, these parameter settings (shown in center highlighted box in Figure 6.2) were used to perform a validation run.

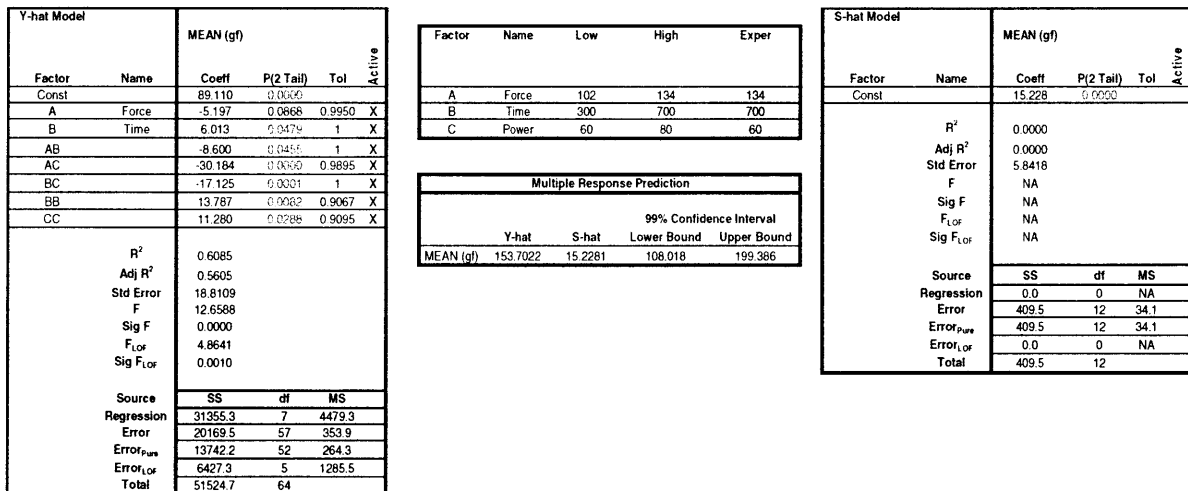


Figure 6.2 – Component B Regression Analysis

Overall, the experiments provided positive results. Validations runs on three out of the four components produced results within the predicted 99% confidence interval and three out of four regression sets of optimal parameters were incorporated into the production process.

²⁸ Formal regression and optimization analysis was done using Microsoft Excel DOE PRO XL, Version 3.0 Build 1, © 1999-2003, Digital Computations, Inc. and Air Academy Associates, LLC. The software allows the user to place a weight on the factors being optimized. An equal weight of 50% was placed on mean and standard deviation for this experiment.

Implementation of these new optimized bonding parameters resulted in an overall increase in bond strength of 83%.

6.5 Lessons Learned

As with most real world experiments the experiment did not take place without its share of problems. Difficulties were experienced from the very first set of runs. Since the experiment did not mirror production (i.e. bonding was done between identical components) relatively weaker second bonds were placed on material previously not exposed to this type of bond. This resulted in either difficulties with bond termination or weak second bonds which contaminated first bond results. To overcome this, second bond parameters were established that produced a very strong (but poor in quality) second bond allowing for proper analysis of the first bond.²⁹

As stated previously, parameter variable values were set at the same level for all four components. At design this seemed like a sufficient approach. However, during the experiment it was discovered that the components behaved very differently from one another. On some components the wide working range initially established resulted in meaningless data at the extreme points due to the lack of bondability at these levels. To overcome this effect, the variable values had to be individually adjusted for each of the components.

Results from component A provided a lesson in the importance of proper parameter settings. Initially, response surface analysis produced statistically insignificant results. Since this was the highest quality and most controlled component this was an unexpected result. Further analysis revealed that, although given a wide working range, the initial values for power did not bracket the optimal setting. Adjustment of the initial variable levels and rerunning of the experiment produced the expected results. This effect can be seen in Figures 6.3a and 6.3b which represent the response surface curve for the two experiments (notice maximum saddle was never reached in initial experiment, 6.3a, due to too low of power settings).

²⁹ Periodic second bond failures still occurred but these data points were subsequently discarded.

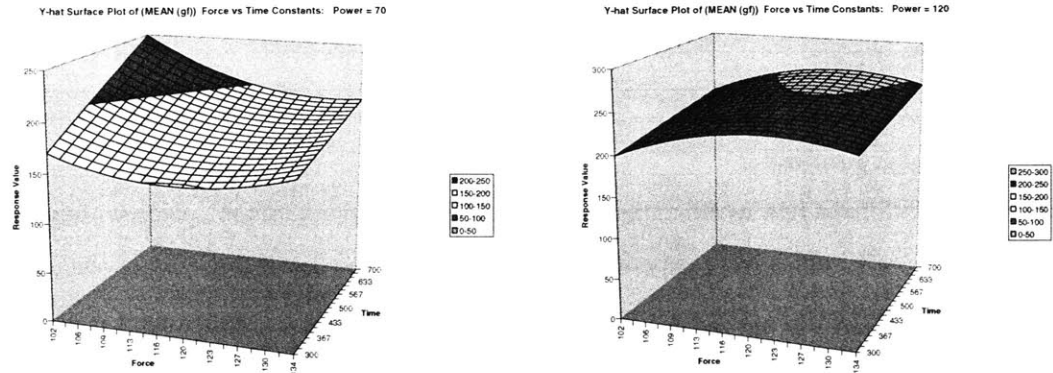


Figure 6.3a & b – Y-hat Response Surface Curve (1st run / re-run)

During initial variable selection it was determined that including bond tool wear as a variable would be not be possible due to time constraints. While this may have been true, experimental results proved that bond tool wear plays a significant role in ribbon bond performance. The impact tool wear has on bonding was discovered during the validation run for component D. After completion of the experimental runs on component D, due to unrelated events, there was a couple days delay before the validation run was performed. When the validation run was performed, results completely unreflective of the experiment were obtained. As it turns out, after completion of the experimental runs on component D, yet prior to performing the validation run, the bond tool was changed due max tool life being reached. Thus, it was concluded that optimal parameter settings differences exist between a new tool and old tool. At the time of the experiment, procedure required a tool change every 20,000 bonds. However, due to the strong dependence of bondability on tool life revealed by this experiment, a process change was made requiring shorter intervals between tool changes.

Lastly, this design of experiments provided further evidence that some small traces of noise still exist in the process. This was most evident in the standard deviation regression results. Of the four components only one produced a statistically significant s-hat model. Even with the successes of this design of experiments, this one piece of evidence proves there is still much room for improvement, particularly in driving component level process control.

6.6 Summary

To maximize the benefits of improved ribbon bonding processes, bonding parameter optimization was achieved through use of a design of experiments (DOE). Bond force, bond time, and ultrasonic power were optimized on four different components using a 3^k ($k=3$), half-factorial design. The experiment proved to be a success as three out of four regression sets of

optimal parameters were incorporated into the production process. Implementation of these new optimized bonding parameters resulted in an overall increase in bond strength of 83%.

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7 Control and Continuous Improvement

Not only is the use of information critical in solving problems but continued data transformation is required to both maintain process control and drive continuous improvement. This chapter focuses on the importance of real-time informational feedback in both monitoring and improving a manufacturing process. The chapter begins by discussing the importance of process control and the use of it at the Integrated Air Defense Center. It then provides a detailed look at a system the author designed and implemented during this work to provide ribbon bonding process monitoring. The chapter concludes with a discussion of the positives and negatives of this system and the future of real time monitoring on the ribbon bonding line.

7.1 Maintaining Process Control

Quality and reliability extend beyond the implementation of new processes. Only through a means of ensuring that processes are maintained can all stakeholders have trust in the delivery of a quality product. Process control is responsible for maintaining quality standards by monitoring and analyzing an operating process. Process control is made of two elements – data collection and analysis. The ability of a process control system to accurately control and monitor the process heavily relies on the time between the data collection and analysis. The greater the lag, the greater the potential for scrap and/or rework (Keats and Montgomery, pp. 41). Thus, the ideal process control system is one that operates in real time. With the advent of automated manufacturing and data collection systems both the data collection and analysis process have made real time functionally possible, but the sheer volume of data collected and information generated has brought new problems to the forefront.

7.1.1 Process Control at Andover

Given that the majority of manufacturing operations at the Integrated Air Defense Center have always fallen under the category of low volume, use of statistical process control (SPC) was not very commonplace. In performing research for this work an example of the use of SPC was found at the Integrated Air Defense Center. The metal fabrication shop used a SPC tool designed using C++ to monitor fabrication of a critical part through automated collection of measurement data. While extensive work was involved in system setup and implementation, the life span of SPC turned out to be fairly short. One of the main contributors to the failure of this process control program was the lack of real time feedback. Because of the delay in engineering/management interface required to provide the proper feedback analysis, the buy-in of operators could never be obtained. Additionally, the non-user friendly operation of the system

overcame what little confidence the operators had left in the system. A third complaint was that maintenance and upkeep of the system was too time consuming for the engineers.

7.1.2 Ribbon Bonding Process Control

One of the major selling points for automated ribbon bonding as the means of interconnection on the radar units is its proven reliability. Due to the critical effect these units have on the end product, ensuring this reliability plays a major role in the ribbon bonding process. Use of process control ensures that this reliability is inherent in the system and not inspected in afterwards. Because of the high volume of ribbons being produced, sampling through destructive and non-destructive pull tests was originally incorporated into the production process as a means of process control.

A large amount of data, representing the strength of the bonds pulled, is collected on each unit. After production ramp-up, a quality movement led what was once initially just data collection into a primitive form of SPC. The data was manually entered by the pull test operator into an Excel spreadsheet where it populated a set of SPC charts. A typical operator would never even see the SPC charts; essentially the operator was only involved with the data itself and not the valuable information that it produced. The only feedback came when the ribbon bonding engineer, who periodically reviewed the SPC charts, discovered an abnormality and as a result discussed it with the ribbon bond operator. What was missing was the real-time feedback that only information could provide. Any requirement for engineering intervention only increases the data to information lag time. Expecting an operator to fully understand and abide by SPC run rules may be a bit lofty; therefore, opportunities for feedback must exist beyond SPC charts.

With these concepts and a need for some real-time feedback in mind, modifications to the existing data collection interface were made. These modifications, mostly in the form of visual controls, focused on providing user-friendly direct information to the user. By making the operators more knowledgeable of the state of the process it gave them the opportunity to alert both the ribbon bond operator and engineer before any problems persisted. The SPC charts themselves, while still automatically being processed upon data entry, became more of a tool used for root cause analysis and continuous improvement.

Learning from the mistakes and pitfalls the metal fabrication shop faced during their implementation of SPC process control, to get the ribbon bond operators on board and promote true real-time feedback, continued improvement of the current system was needed. Without further modifications the system was heading down a path of eventual failure. Even with the current improvements to the system in place the lag time of the most valuable information (that

from the SPC charts) was still so great that the operators did not treat the system as a means for providing process feedback. The system was regarded simply as a means for collecting data just in case it might be needed in the future. Secondly, since the system was basically a large spreadsheet, daily maintenance by the engineers was very labor intensive. Lastly, because the system required manual entry of all data, the data entered often was inaccurate or incomplete.

7.2 Automated Bond Pull Interface

To overcome the challenges faced with trying to implement a lasting system of process control, a new automated ribbon bond pull test data collection and analysis system was developed by the author over the course of this work. The goal of this system was to provide the bond pull operator an interface that was user-friendly and through extensive use of visual tools and controls provided real-time ribbon bonding process feedback. The system uses SPC as its basis yet much of the real-time feedback is not in the charts themselves but in information pulled from the control charts.

The system, labeled the Bond Pull Test Interface, was developed in-house using a software program called Labview. This software was chosen because it was being used at the Integrated Air Defense Center as part of a movement to bring the plant closer to a visual factory. One of the selling points, but also a major stumbling point in both design and implementation since it required extensive customization, was the system's ability to automatically capture previously manually recorded pull test data. This feature was important for several reasons. First, since the interface replaced a manual task it represents a labor savings. Secondly, since the data entry step is no longer required the operators can focus more attention to the actual information produced by the data rather than the data itself. Thirdly, it eliminated the potential for data inaccuracies and incompleteness.

The interface was designed to meet the needs of both the operators and engineers. To provide concise, real-time feedback to operators, summary screens incorporating visual controls were used. Within these summary screens layers and layers of information (including SPC charts) are available to provide an engineer with all the necessary information needed for more detailed process capability monitoring.

7.2.1 Interface Screens

Four different types of screens make up the heart of the Bond Pull Test Interface – data collection screen, bond monitor board, bonding score card, and SPC charts. The data collection screen (Figure 7.1) is used to automatically capture data generated by the pull test machine. Even

with this very first screen, data is transformed into information providing operators process feedback. As the data comes across it is compared with SPC limits and the results are tagged with a label defining where they lie in regards to the SPC chart.³⁰ The bond monitor board (Figure 7.2), used by both operators and engineers, provides a daily summary of bond force mean and standard deviation and provides visual feedback as to whether the data lies within the process control chart limits. From this screen operators and engineers can obtain more detailed daily information by double clicking on a specific bond wire set. The bonding score card (Figure 7.3) once again uses extensive visual tools to highlight where individual data points lie with regards to SPC charts as well as providing easy to read summaries of failure modes. The fourth screen is the actual SPC charts (Figure 7.4). With a single click control charts can be generated from either the bond monitor board or the bonding score card for any of the six wire sets.

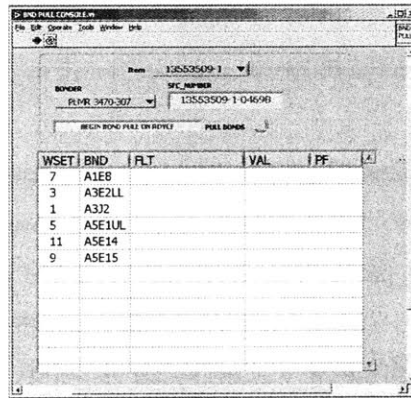


Figure 7.1 – Data Collection Screen

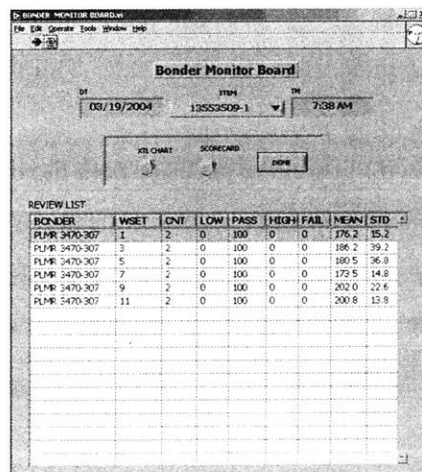


Figure 7.2 – Bond Monitor Board

³⁰ The current version of the interface shown in Figure 7.1 only generates a column that defines where the results lie on the SPC chart. Future versions of this interface will include more elaborate visual controls such as color coding.

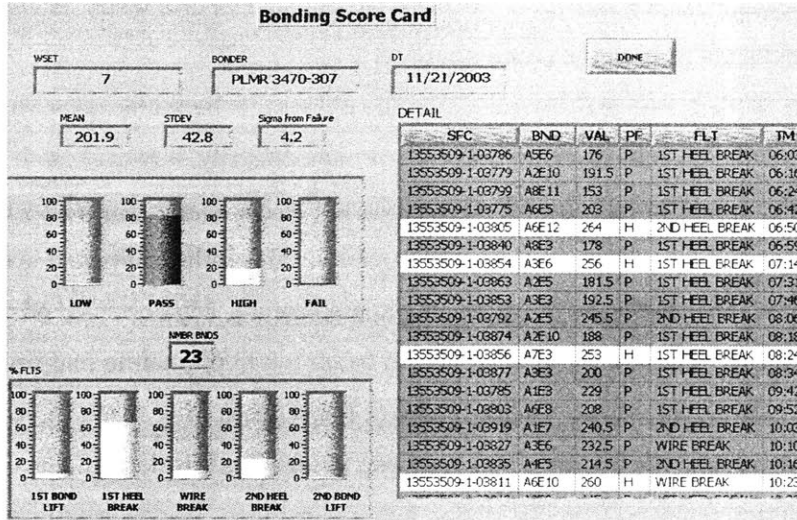


Figure 7.3 – Bonding Score Card

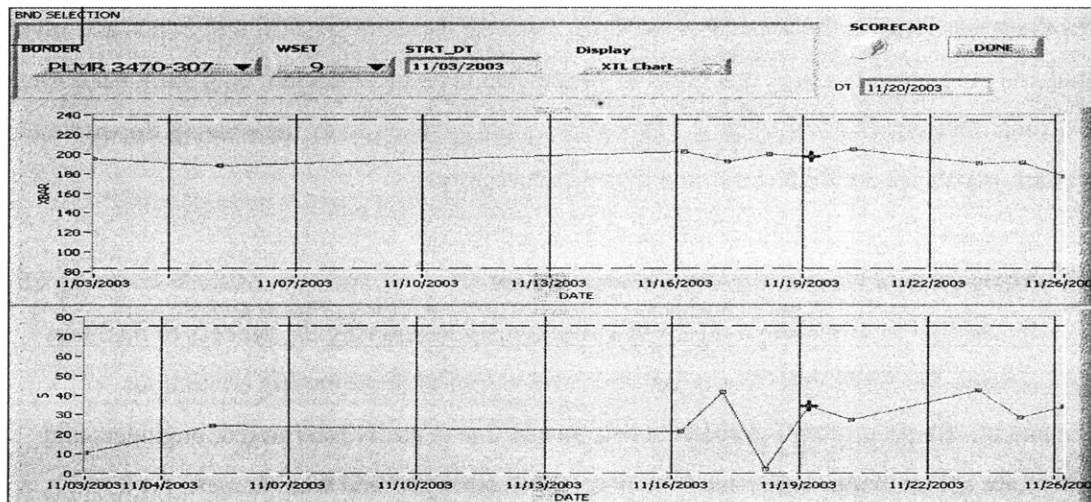


Figure 7.4 – SPC Charts

7.2.2 Interface Pros and Cons

Overall, the new system has led to improved capabilities with regards to process control. Because it was designed to be user friendly, the interface was well received by the operators making for a relatively easy implementation. The use of visual controls to present information has made interpretation of the results easier, promoting real-time feedback. Automation of data collection has not only been embraced by the operators who previously were tasked with manual data input, but it has also generated an extensive and accurate database. For the engineers, review of process capability is much easier as well. Information once stored mostly in the form of data in several different files is now available in one program readily customized for any given date or

bond type. In general, the system now presents information that can efficiently and effectively be used to monitor the current state of the process.

The system, while a vast improvement over the old way, is by no means perfect. As stated before automated data collection helps to ensure data integrity, however, under certain unusual situations this can be compromised. Given that the interface was essentially retrofitted to collect data on a manual system there is a lack of flexibility. This inflexibility can lead to cases where data is captured incorrectly and due to the automated nature only corrected afterwards through database editing. The new system has done a better job in promoting real-time feedback, however, given the current process set-up this feedback is not necessarily to the right person. Currently, the operator using the interface and receiving the feedback is the pull test operator. This operator is one step removed from the ribbon bonder operator. Thus, unless he/she immediately communicates the information to the ribbon bond operator any real-time feedback is lost. Lastly, while the SPC charts are relatively user-friendly, the quantity of charts available makes them less likely to be used. For example, because there are six different bonds and several manual and automated bonding machines in which data is being collected, on a daily basis there are over ten different charts to review. This sheer quantity takes away the relative importance of each chart, makes for a tedious task, and thus discourages use.

7.3 Interface as a Continuous Improvement Tool

In addition to providing a means of continuously monitoring the process to maintain process control, the Bond Pull Test Interface is also essential in promoting continuous improvement. By presenting information in a format that is easily interpreted, engineers and operators are able to better understand the process, its strengths and weaknesses. As a result, a constant focus on improving as well as monitoring the process becomes a daily norm. Additionally, because an extensive amount of data history is being collected and managed, root cause analysis becomes much easier leading to more incentive to solve problems and quicker solutions.

7.4 The Future of the Bond Pull Interface

As the tool promotes continuous improvement, improvements of the interface tool itself are a fruitful endeavor. Probably the biggest area for improvement is in taking steps toward true real-time process feedback. As mentioned earlier, the bond puller and not the bonder is currently receiving the feedback. In order to directly gain from the information being processed by the interface, the bonder should be able to, in real-time, receive feedback on how the machine is

operating and make any adjustments accordingly. A simple and realistic solution to this is installing a monitor board near the bonder that displays relevant SPC charts and summary data.

With constant improvements being made to the process, a reduced frequency and quantity of sampling is required. Less sampling drives a change in the development of SPC charts. For example, less sampling frequency may result in a shift from X-bar charts to individual charts and a reduction in sampling quantity may reduce the total number of charts. Nevertheless, since the system uses SPC as its basis it is important that the methodology used to analyze remains consistent with the sampling methods.

Lastly, continued improvement on the use of visual controls is a must. In a multivariate process such as ribbon bonding, it is important to keep an eye on the big picture and not get lost in the details. In such a detailed process the only way to promote real-time process monitoring and improvement is by keeping output simple and straight forward. Visual controls can do just that and the more they are present the more they will be used.

7.5 Summary

To ensure quality and reliability are inherent in a process, a means of maintaining process control must be in place. One of the outcomes of this work was the successful design and implementation of an automated ribbon bond pull test data collection and analysis interface. This interface, design and implemented by the author, was developed to provide a user-friendly interface that automatically collects data and generates real-time process feedback. Implemented in November of 2003, it replaced a manual method of data collection and improved the effectiveness of process monitoring and control. However, initial implementation of this interface was only the first step. Many opportunities for improvement of this system exist and are necessary to bring the ribbon bonding process closer to full utilization of real-time process monitoring and feedback.

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8 Managing the Change

This chapter shifts focus a bit as it looks at the softer side of the process improvement changes that took place at Raytheon and in the ribbon bond room. The chapter, with portions written in the first person, reflects on the author's experiences during this work and how organizational processes affected how change was made. By analyzing the importance of good team dynamics and the organizational structure being affected by change, we are able to better understand the contributing factors that led to success over the course of this work.

8.1 *An Inevitable Need for Change*

One of the greatest advantages in regards to leading a change effort this situation brought is that in some form or another change needed to happen. Given the current state of the manufacturing line, deadlines were likely not going to be met and money was bound to be lost unless something was done. The challenge for me therefore became figuring out how to institute long term change when the stated problem only addressed a need for a short term solution.

When I arrived a firefighting "red" team had already been established. Their goal was simply stated, fix the ribbon bond problem. With the problem being low rates and low yield it was evident that changes needed to be made. Whether it was the simple solution of buying more equipment and/or working extra shifts to increase capacity, or the more difficult solution of determining the root cause and making process adjustments accordingly, or a combination of the two, changes needed to be made. Upon my joining, the team had already made some strides towards understanding the problem and had pretty much begun taking the combination approach. At that time the goal of the team was of first priority to overcome the pressing issue of being the line bottleneck, and of second priority to fix the problem so that it didn't recur on follow-on radars.

After spending some time working with the team and learning more about the hidden reasons that led to this situation and made solving it more difficult, I realized that while accomplishment of the team's goals were sufficient to get through the current crisis much more work was needed to solve the real long term issues. More than just process changes, changes in the way data is collected, information generated, and decisions made were critical in achieving long term results.

8.2 *The Role of the Team*

As previously mentioned, due to the high visibility and the urgent need for a solution, prior to my arrival, the decision was made to assemble a team to combat the ribbon bond

problem. The team was made up of about ten individuals which included subject matter experts, manufacturing engineers, materials engineers, and middle managers. Looking back, the formation of a team was one of the most important factors in successfully bringing about change. Having the strength of a team became beneficial in driving both the changes needed to solve the immediate technical problem as well as implementing the initiatives presented in this work that will lead to long term improvements.

8.2.1 Team Structure

An important contributing factor to the success of the team in implementing change was the team's structure. Almost as important as the knowledge that each member brought to the table was the wide representation of stakeholders that populated the team. Because each of the critical stakeholders was well represented, all individuals affected by the change were involved in all of the decisions. While this did not completely eliminate resistance to change, the resistance was usually felt early in the change process and thus slight course modifications could be made before the resistance grew too strong.

In addition to critical direct stakeholders, there were also individuals on the team that were not direct stakeholders. The team included individuals that were not directly involved with the radar program and thus were not necessarily incentivised to find a quick fix and get the product out the door. This was a very important factor because these individuals remained unbiased throughout the change process and were willing to resist the short term, simple solution and force the right solution even if it slowed the process.

I was not brought in specifically to become a member of the team. My task was to find a way to help the organization solve the ribbon bond problem. After learning that this team existed I realized that it would only be beneficial to my work to leverage the abilities, credibility, and resources that the team had to offer. After my first meeting with the team it was evident that our two interests were well aligned. My role with the team was to bring outside thought in. I was able to bring a strong voice to the table because even more than the indirect stakeholders I truly had an unbiased view. Because I was theoretically not an employee of the company, I was free of any politics that might effect how decisions were made. I was able to provide my input without any concern as to how it would affect my position in the company. Because of this, I became a valuable asset to the team and at times became the necessary scapegoat to move forward.

8.2.2 *Advantage of a Team*

One measurement of a successful team is that its whole is greater than the sum of its parts. The ribbon bond team clearly fulfilled this requirement. The team was very good at leveraging each others knowledge and capabilities. Since many of the members had been in the industry for several years, the amount of both internal and external resources available was immeasurable. The members of the team had such strong credibility that any proposal or recommendation from the team was generally accepted by outsiders without second guessing. This made for once again an easier task in managing the change. Most importantly the existence of a team strengthened the decisions made. These decisions represented the thinking of ten individuals and were treated as such.

The successes of this work would not have existed without the involvement of the team. Many of the initiatives of this work involved thinking out of the box and taking risks. Thus, without having the ability to leverage a team to help gain momentum and earn buy-in none of the initiatives would ever have made it off the ground. My role was to bring outside thought in and the team provided an open ear for this thought.

8.3 *Organizational Structure*

In analyzing the implementation of a change initiative it is important to understand the dynamics of the organization affected by this change. An approach to analyzing the behavior of an organization is to study it from three different perspectives. This approach presented in a paper by John Carroll, "Introduction to Organization Analysis: The Three Lenses" defines these perspectives bases on three lenses: The Strategic Design Lens, The Political Lens, and The Cultural Lens. Each of these lenses provides a different way of thinking and allows the observer to gain new insights and a richer picture of an organization (Carroll, pp. 3).

8.3.1 *Strategic Data Management Barriers*

The strategic design view focuses on formal structure and strategy of an organization. Individuals or groups that operate under this perspective operate based on rational analysis and act in accordance with a vision. Of the three lenses this view had the smallest impact on the ribbon bonding change initiatives.

The strongest evidence of the strategic lens perspective playing a role involved the resistance to change with regards to the data management system change initiatives. The current shop floor data management system, a carry over from another Raytheon facility, was installed with the intention that although it did not completely align with the structure needed on the floor

modifications would eventually be made to bring this alignment. An overall strategy was established by IT and a plan developed to accomplish this task. In order to fully accomplish the initiatives of this work, changes to the current data management system were required. These changes would essentially accelerate the modifications to the system and thus disrupt IT's current plans. Because of this disruption, the required change initiatives were met with strong resistance. The barriers to change were so high that under the time constraints required by this work in most instances temporary alternative solutions became the norm.

From this work it became evident that there are some long term changes that need to be made with regards to the data management system. Yet, overcoming the strategic plan of the organization is the first step to be taken. Accomplishment of this can only be achieved through eventually breaking down the barriers and establishing an alignment between the manufacturing floor and the data management system.

8.3.2 Political Alignment Differences

Viewing an organization through the political lens provides an examination of potential power struggles between various stakeholders due to their different and sometimes conflicting interests. Overall, at Raytheon, with regards to the ribbon bond problem, interests were relatively aligned amongst all levels of the organization. Only in rare instances were there indications of a power struggle. Figure 8.1 demonstrates this alignment through a stakeholder map. However, it goes without saying there were differences, and these differences brought with them difficulties in change implementation. In order to understand this perspective it is important to analyze the key organizations involved with the potential change initiatives. These organizations include: Raytheon Integrated Defense Systems, the Integrated Air Defense Center, the radar program office, the ribbon bond team, engineering, and the union labor force.³¹

³¹ Although there is overlap amongst these organizations, each operates under its own strategies and goals.

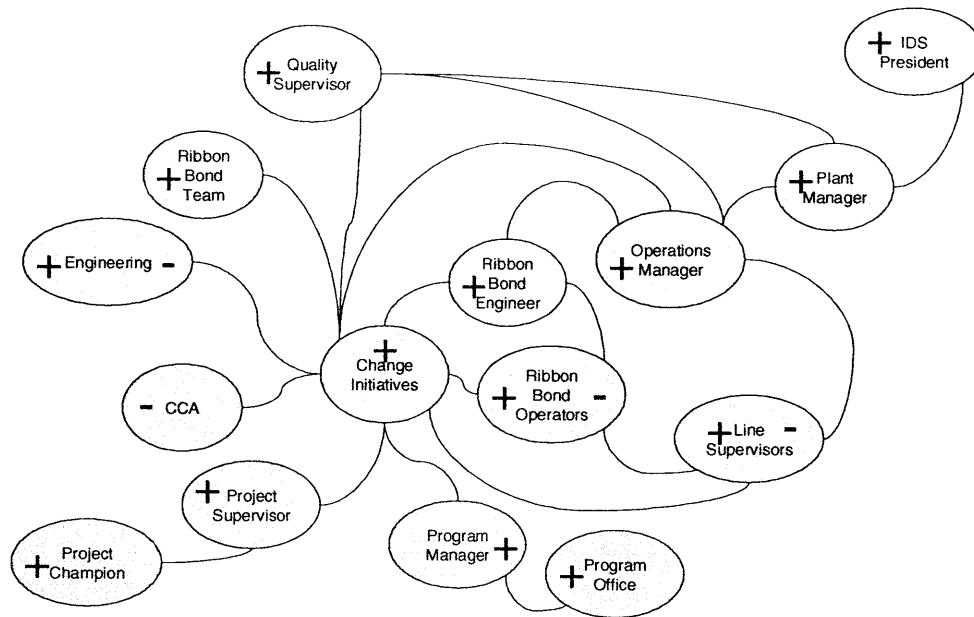


Figure 8.1 – Stakeholder Map

This new radar product line is extremely important to the Raytheon Integrated Defense Systems (IDS) business unit. It represents a potentially strong line of business over the coming years. Therefore, the overall success of this program is extremely critical and any potential issues are made known to the highest levels. One of the top initiatives coming down from the President of IDS is a focus on trimming the cost of producing these radars. Because the change initiatives resulting from this work were based on cost reduction, they were very well aligned with the overall business unit strategy. This alignment played a critical part in getting the right resources and appropriate funding to achieve the desired success. With support coming from top down, managing of the change became a lot simpler.

Similar to Raytheon IDS, this new line of radars is very important to the Integrated Air Defense Center. The surface radar product line represents the future of Andover manufacturing. Failure in delivering a quality, on-time radar could easily equate to a loss of business for the facility and even a potential plant shut down. Consequently, as with IDS, this program was given very high visibility. As an example of this level of visibility, on a weekly basis the plant manager was given a personal briefing on the status of the manufacturing line which included a detailed status of the ribbon bond problems and change initiatives. In contrast to the business unit, the Integrated Air Defense Center's radar screen was set to a much closer range. Even though the future of the facility involved success over the long run, much more emphasis was put on short term success. The most important thing to this organization was getting the first radar delivered

on time. Although at times this affected the success of the second radar, the attitude was more of “we will worry about that when we get there, because if we don’t succeed now we may never get the opportunity later”. This strategy did not align well with the initiatives of the ribbon bond team and this work which were more focused on the long term solution. Evidently, since in most instances of change things usually get worse before they get better, there was some resistance to change.

The program office was centered on one goal, making the customer happy. Whether this meant delivering product tomorrow or a higher quality product next month, it was the voice of the customer that drove most decisions. This strategy served well at times for the change initiatives but also drove resistance under certain occasions. Since the discovery of a ribbon bond solution could potentially make or break the successes of the radar, the program office was in full support of the team’s initiatives. No matter what the request, as long as it drove closer to a solution, it was easy to gain support, whether financial or resource, from the program office. In contrast, because the customer represented only his radar and not necessarily future radars, the focus was short term. This put pressure on the team to find a solution now regardless of whether it was the best decision for the long term. Again, any forward thinking change initiative, especially those that slowed short term success, was met with resistance.

The ribbon bond team’s goal was to solve the ribbon bond problem. This involved both a short term as well as long term strategy. In other words, the goal was not only to rid the current bottleneck, but also determine and fix the root cause so this problem does not reappear on subsequent radars. To accomplish this, the team had to develop a strategy that would alleviate the short term pressures while allowing them to develop a long term solution. This strategy was a difficult one because in most cases the long term solutions hindered short term solutions. Adding to the difficulty was the fact that the team was aligned in various ways with the organizations supported by and supporting them. This made managing of change difficult as the team was pulled in many directions thus deflating the strength of the initiatives.

Although not necessarily a result of misalignment, the engineering organization brought the most resistance to change. Probably best described as an example of a power struggle the engineering organization throughout the scope of this work constantly became the roadblock in the change process. With a goal of producing the best design for all radars, this strategy was very well aligned with the initiative. However, the organization was in constant disbelief that their design was faulty. Any recommendation for improvement was treated as a threat to their design and thus was always initially met with resistance. Any acceptance of change was only obtained after an overly detailed analysis proved that this was the right way. With the team operating at

times under a strategy of trial by fire this resistance became only greater. Overcoming this resistance usually meant compromise. Fortunately, since there was a member of engineering on the team compromise became in most cases a win-win situation and rarely derailed the ultimate goal.

The goal of the labor force was to successfully accomplish their task at hand (build a quality product, on-time) in a positive work environment. Because it was felt that the change initiatives would disrupt this goal, they were mostly met with resistance. The constant challenge became finding a way to convince the workers that these initiatives were in alignment with their own goals. Persuading them to believe that these new processes were being put in place to make their life easier was never an easy sell. As a result, until evidence could be put on paper that the new way was better, the resistance did not go away.

In every organization strategic misalignment will be present amongst internal organizations. Thus, when implementing a change initiative it is important to understand this misalignment and structure the change to provide the right incentives that bring alignment closer and decrease the inevitable resistance to change.

8.3.3 A Cultural Change

By taking a cultural perspective we are able to identify the symbolic system of meanings, values, and routines that dictate an organization's actions. In Chapter 1 of this work we began to describe evidence of the major cultural changes that the Integrated Air Defense Center was facing as a result of a new line of radar products. The old "low-volume" manufacturing culture was quickly being transformed into a completely new way of thinking and acting as dictated by a high-volume manufacturing line. Propelled by the need to overcome challenges, the initiatives of this work forced an acceleration of this cultural change.

The "low-volume" culture of the Andover manufacturing facility prior to the introduction of this line was established as a result of many years of operating in a slow-paced, low-volume environment. From the factory floor to the managerial offices actions and decisions were greatly influenced by this culture. For example, in a low-volume manufacturing culture a product line may produce an output of several units per month. Since the number of total defects could essentially be counted on one hand there is no requirement for an elaborate system of recording defects and developing metrics to categorize these defects. Defects, as well as parts, are treated on an individual basis, thus any record is most likely kept with a log that remains with the product throughout its manufacturing life. Similarly, in most instances decisions made in a low-volume culture affect only a handful of product. Thus, any urgency to make a decision is removed. As a

result decisions are never made strictly for the purpose of moving forward. They are only made after thorough, complete evidence is obtained and all parties involved are in favor of the decision.

Cultures are not easily changed. Thus, even as the world within the Integrated Air Defense Center began to change, the attitudes, beliefs, and actions remain embedded in this low-volume manufacturing culture. Although the new environment could be in comparison defined as a high-volume manufacturing culture, evidence of a low-volume culture remained fixed. Being stuck in this culture only exacerbated the problems the line was facing and brought strong resistance to initiatives developed to correct the problems. The change initiatives of this work felt this cultural struggle.

8.3.3.1 Decision Making

Probably the most significant cultural adjustment brought on by this new culture is the way in which decisions are made. In a high-volume manufacturing culture in which every day new products flow in and out of the line, decisions can not be made at the low-volume pace. Every day a decision is delayed results in more and more product being affected by the lack of decision. One of the attributes that led to the success of the ribbon bond team is that they quickly adjusted to this new culture. A contributing factor that drove this cultural shift was the availability and use of information. By basing decisions on data driven information the team became confident in making quick decisions that allowed the team to press forward in their problem solving approach. This drove confidence in the team and resulted in more and more instances of taking risks and challenging of the status quo.

This new thinking, however, was not met without resistance. Although the team had been able to transition into this new active decision making mentality, not all organizations involved had matured as quickly. Engineering, for example, who inevitably always has a say in the final decision making process, was not as easily adaptable to this change. In several occasions a movement forward by the ribbon bond team was promptly put to a halt by engineering. Even after presentation of pertinent information they always seemed to insist on more information and more time. In most cases it was not because the “right” information wasn’t there in the first place, but because they operated in a culture that believed given time things will eventually work themselves out.

8.3.3.2 Data Collection and Management

As daily product flow increases, the need for a systematic means to collect the data also increases. Given the high volume of data now produced, for the visual tools introduced in this

work to become self-sustaining they must become reliant on these types of systems. During this work, however, this shift faced a constant struggle. The current systems were a product of a low-volume environment and modification required a completely new way of thinking. For instance, in a high-volume environment, data collection is done automatically in a standardized fashion. A low-volume culture encourages individualization, thus resulting in a loss of consistency from one data point to the next. Making this transition not only requires new data management tools but also a shift in a culture accustomed to personalizing every bit of data. Experiences from this work showed that before the low-volume culture mindset can be shifted the tools must be transitioned, yet to shift the tools an understanding of the new mindset must occur as well. This chicken before the egg syndrome is what brought resistance to the initiatives of this work and consequently slowed any real change in the overall data management system.

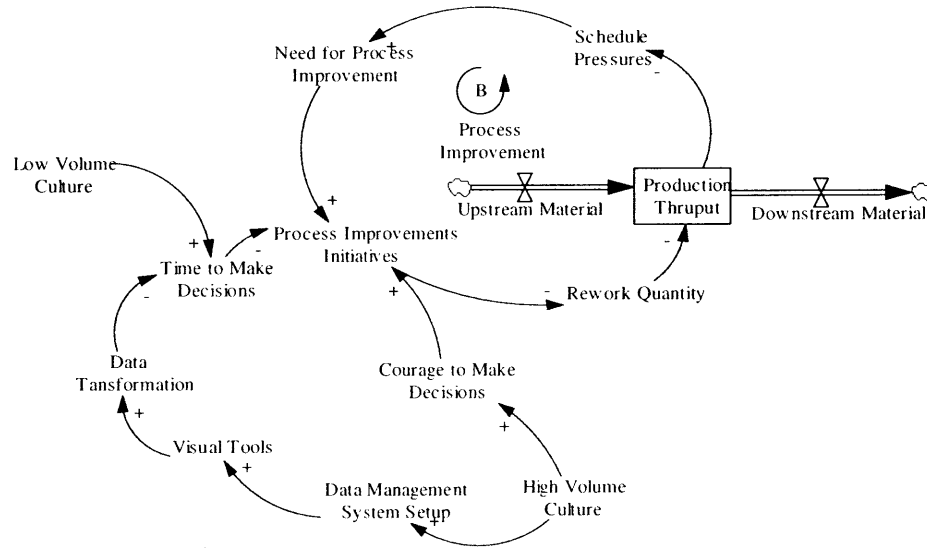
8.3.3.3 Process Monitoring

In a low-volume manufacturing culture an exact process is rarely repeated. Products are treated as individuals, not as just a part number, and thus comparison between one another is not commonplace. The occurrence of process monitoring in a low-volume manufacturing culture thus rarely exists. Implementation of a system of real-time process monitoring that this work introduced therefore did not go without resistance. Operators could recognize the occurrence of a problem on a unit, however, the low-volume culture mentality prevented development of a relationship that a problem on one unit may result in a problem on the next unit. To the operators SPC charts are just another chart; and real-time feedback will only occur when a shift in cultural thinking occurs.

8.3.4 System Dynamics Model

How the organizational structure has had an effect on the ribbon bond problem and the initiatives that helped lead to process improvement can be summarized in a systems dynamics model (Figure 8.2). As the model shows, the heart of the problem, low production throughput, is ultimately driven by the quantity of rework. The success in driving down this rework is a function of the success of the process improvement initiatives. The remnants of a low-volume culture, particularly in the engineering department, and its part in delaying the time it takes in making decisions, ultimately worked against this success. However, institution of high-volume cultural thinking that was achieved by the ribbon bond team counteracted and overcame this effect. The high-volume thinking of the team led to implementation and use of new data management tools, leading to information based decision making. Also, the high-volume mindset

drove risk taking decisions that were needed to move forward. As a result the team was able earn the support of all stakeholders leading to successful change implementation, reduced rework, and increased production throughput.



8.2 – Process Improvement System Dynamics Model

9 Conclusion

Over the course of this work several successful initiatives were accomplished leading to an improved ribbon bond process, but more importantly many lessons were learned. This chapter provides concluding thoughts that summarize the institution of change leading to these lessons. It focuses on a discussion of the key element of this work transforming data into information and the potential for continued use of this methodology. It concludes by providing an update of the ribbon bond line three months after the conclusion of this work and gives examples of how the lessons learned from this work have been critical in continued improvement of the process.

9.1 Transforming Data into Information

One of the positives and negatives about a multivariate process such as ribbon bonding is the enormous amount of data that is available. If used effectively this data can provide the answers to reasons for instances of failure or just give an overall indication of how the process is operating. However, the real challenge is developing a means of using this data effectively or in other words transforming this data into information.

Over the course of this work we were able to successfully accomplish this data transformation. This transformation led to the elimination of a major yield and throughput problem on the manufacturing line of radar units. This transformation did not come naturally. It involved extensive manual efforts necessary to shape both the way data was taken and analyzed and the way decisions and actions were made based on this new information. Development and use of visual tools were at the forefront of this transformation. Visual tools were effective because they were user-friendly and told the story in a clear, concise manner. However, unless data is taken in a compatible format, generation of visual tools and transformation of data is not possible.

9.1.1 Barriers to Transformation

The concept of using information instead of data to understand processes and solve problems is one that can be used in many different areas. However, in order to successfully accomplish this in the future there are two areas that IDS Operations/Andover must focus on. The first is continued improvement of the data management infrastructure and the second is a further shift towards a high-volume culture.

9.1.1.1 Infrastructure Changes

One of the major problems in incorporating visual tools and the transformation of data into information during this work was overcoming the current data management infrastructure. Under the current system, data is taken in non-standardized formats or in software programs that are not compatible with easy data analysis. Development of visual tools thus required extensive manual intervention.

Some of initiatives of this work represented a start to this change in infrastructure. However, most of them were slowed by the current infrastructure. One of the initiatives that was successful in self-sustaining data transformation was the Bond Pull Test Interface. This tool, however, was custom designed and did not require use of the current data management infrastructure. Therefore, implementing this tool in another area would require extensive work. In order for IDS Operations/Andover to be successful in overcoming this barrier the current data management system needs to be restructured in way that improves the methods of data collection. Only with data in the right format can transformation be made possible.

9.1.1.2 Cultural Changes

Having the tools available is only part of the data transformation processes. Utilizing the information produced to make decisions is the second step in the process. In the low-volume manufacturing environment that previously existed at the Integrated Air Defense Center, data transformation was not critical to successful operations. However, in the new high-volume environment that now exists, the amount of data generated is enormous. Unless this data is transformed into information, any potential value gained from the data will be lost. Unfortunately, IDS Operations/Andover has been slow in understanding the power in using such information. Thinking and acting is for the most part still done in low-volume terms. Until IDS Operations/Andover completes a shift in its mindset to that of a high-volume culture, it will never completely utilize this information resource.

9.2 Lasting Effects

In any change initiative one of the common fears is that within months of the change things will start to drift back to the way they were before the change occurred. One of the advantages of some of the ribbon bond change initiatives that may prevent this effect from occurring is that actual process changes were incorporated. However, just as important as these physical changes are the cultural mindset changes that this work attempted to instill.

Three months after the conclusion of this work, with regard to the physical process changes that took place, there is indication that things have not reverted and progress continues to be made. The cleaning and heating processes are still in place and bond strengths remain at the levels they were three months ago. The amount of failures at initial bonding and at test, and thus the amount of rework, is also at the same improved levels.

Continued use of data-driven information in problem solving has also occurred over the three months providing evidence that there were valuable lessons gained from the methodology utilized during this work. In one instance, there was a concern that ribbon bond lifts were becoming the major culprit to an increased number of failures occurring at test. Current pull test strengths and the measured process capability indicated that bonds were at the levels that would not predict this quantity of failures. To better understand what was occurring, a visual tool developed during this work was used (fault location mapping) that showed the distribution of failures. Results indicated high densities of failures at the outer edges, providing evidence that failures may be caused during a thermal or vibration test. Test runs were subsequently performed and results showed that the stress regimen was indeed the culprit and the problem was solved. This is a sterling example of the power of information and visual tools.

In a second instance, failure at a joint led engineering to believe that the failure could be “traced” to a rise in heat caused by ribbon bonding the radar units with heat. Confident in its process and the information that led them there, the ribbon bond team demonstrated to the rest of the community that turning down the heat is a bad thing. Sticking to their ground the team went on to prove heat was good and identified mechanical stress as the culprit.

Through continuous application, such as in the examples above, of the learnings presented in this work, IDS Operations/Andover as well as other organizations when faced with process improvement problems will hopefully not only solve the existing problem but set groundwork for improved problem solving in the future.

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