The Development and Implementation of Process Control Strategy on a Vehicle Launch

By

Heather M. Lindell

B.S. Mechanical Engineering, GMI Engineering & Management Institute, 2002

Submitted to the Department of Mechanical Engineering and the
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Signature of Author________________
May 6, 2005
Sloan School of Management
Department of Mechanical Engineering

Certified by______________________
Jan A. Klein, Thesis Advisor
Senior Lecturer of Management Science

Certified by______________
David E. Hardt, Thesis Advisor
Professor, Mechanical Engineering and Engineering Systems

Accepted by______________________________
David Capodilupo
Executive Director of Masters Program
Sloan School of Management

Accepted by____________________
Lallit Anand
Chairman, Committee on Graduate Studies
Department of Mechanical Engineering

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Abstract

This thesis delves into the strategic and organizational challenges of implementing process control plans for a vehicle launch. The author explores the development and implementation of process control plans employing lean philosophies such as Standardization, Built-in-quality, and Continuous Improvement. This thesis is based on the work of a seven month internship at an automaker. The focus of the internship was the development and implementation of process controls in the body shop of an automotive assembly plant. The process control strategy focuses on specific areas such as the dimensional control of the body-in-white assembly and the weld monitoring process, where solid control strategies are vital. The internship supported the launch of a new passenger car, though references to the automaker and assembly plant have been removed.

An organizational change analysis of the process control initiative is offered. Finally, lessons learned and recommendations for change management and continuous improvement of the process control initiative are presented.

Thesis Supervisor: Jan A. Klein
Title: Senior Lecturer, Management Science

Thesis Supervisor: David E. Hardt
Title: Professor, Mechanical Engineering and Engineering Systems

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1.0 INTRODUCTION

This thesis delves into the strategic and organizational challenges of implementing process control plans for a vehicle launch. The author explores the development and implementation of process control plans employing lean philosophies such as Standardization, Built-in-quality, and Continuous Improvement. This thesis is based on the work of a seven-month internship at an automaker. The focus of the internship was the development and implementation of process controls in the body shop of an automotive assembly plant. The author approached process control plans as consisting of five key steps:

1) Define the process and owners
2) Define the upper and lower control limits
3) Utilize six-sigma techniques to interpret trends
4) Set alarm limits with varying degrees of severity
5) Define the reaction plan and owners

The process control strategy focuses on specific areas such as the dimensional control of the body-in-white assembly and the weld monitoring process, where solid control strategies are vital. The internship supported the launch of a new passenger car, though references to the automaker and assembly plant have been removed.

To protect the confidentiality of the automaker, this thesis will refer to the company as the Automaker. The production site will be referred to as the assembly plant.

1.1 Situation/background

In the spring of 2004, the Automaker launched a vehicle crucial to the automaker's product portfolio. The new vehicle represented an entirely new product build for the assembly plant. The previous models being built at this plant were phased out, and the new vehicle became the sole product of the plant. With such a major plant overhaul and new vehicle launch comes major product and process integration challenges. Thus, an intense initiative to build-in high quality during the assembly process is crucial. The focus of this internship was to develop and implement process control plans to support built-in quality of the new product during the launch and into regular production.

1.2 Problem/Challenge

The core problem addressed by this thesis is the necessity for process control in the body shop of an automotive assembly plant. Process control is vital to the success of a launch as it accomplishes four key goals:

- Minimizes reactive activity by concentrating on preventative behavior
- Minimizes spending on rework and repair
- Minimizes the number of parts requiring rework or repair in the system through built-in quality and part monitoring
- Ensures the dimensional quality of the vehicle

1.3 Approach/Method

Qualitative data was gained through benchmarking five automotive assembly plants, and interviewing and shadowing members of the dimensional engineering community at each plant. Internal and external industry experts were interviewed regarding trends in process control strategy. Academic research was also performed.

Upon obtaining a solid understanding of control strategy, current processes within the body shop were evaluated based on their need for process control. Several processes were identified as areas that required control strategy such as weld monitoring, cap changing, and tip dressing. These current processes were evaluated and control strategies were created and implemented.

As explained in section 1.0, process control plans implemented at the assembly plant consisted of five key steps.

1) Define the process and owners
2) Define the upper and lower control limits
3) Utilize six-sigma techniques to interpret trends
4) Set alarm limits with varying degrees of severity
5) Define the reaction plan and owners

Furthermore, the In developing these steps, the author and newly formed process control team incorporated principles of Lean Engineering, such as standardized work, standardization, and built-in quality. Quantitative data was collected through in-plant measurement systems such as laser systems and hand gages. For confidentiality purposes, documentation and data are undisclosed.

1.4 Results/Solution

The author's internship at one of the Automaker's assembly plant produced significant strides in body shop process controls in the following areas of the body shop:

- Dimensional Control
- Weld Monitoring Process
- Tip Dresser Preventative Maintenance
- Weld Cap Change Process
- Sealer Process Control

Each of these areas, to varying degrees, experienced a refinement in their control strategy. The resulting control strategies are leaner, more efficient, and more effective. Numerous employee/work place safety initiatives were also identified and resolved to facilitate more effective process monitoring.

A final result of this thesis was to create an awareness of the necessity for process controls via routine process control meetings, visual controls on the floor, and training materials. By the end of this internship, a "pull" for process controls prevailed throughout plant and body shop management. This "pull" for process controls was evident by plant management demanding that process control was to be the number one priority for the body shop.

1.5 Conclusions/Key Lessons Learned

Both technical and organizational lessons were realized through this internship. The major themes are as follows:

- When incentives are aligned only to support production schedule and volume, quality often suffers. Process controls are neglected.
- Process controls can be successfully implemented utilizing lean principles.
- The corporate culture and organizational behavior of a plant dictates the effectiveness of process controls.
- The reactive mentality is engrained in the culture of many plants, and preventative behavior is something that must be learned and rewarded.
- When workers are involved and empowered, process control implementation has proven successful and sustainable.

2.0 INDUSTRY TRENDS IN PROCESS CONTROL

The evolution of the automotive industry has produced a more sophisticated buyer. Whereas the automobile at one time existed to simply move a person from point A to point B, vehicles have taken on a new level of functionality and aesthetic value as well. Not only is a buyer concerned with the vehicle's specification, but her eye is keener. She is attuned to visual cues from both the interior and the exterior of the vehicle. Therefore, it's not just what's under the hood that matters. It is often the impression, or the feeling that a vehicle gives a buyer that could make or break a deal. Therefore, the look and the feel of the vehicle are paramount. As one Forbes writer commented, "Buyers have to feel like they are getting a good car, whether they are or not, something automakers call 'perceived quality.'"[1] Buyers perceive their vehicle's quality through a number of factors including reports they've read, such as JD Powers reports. Many automotive critics would say that a buyer's impression of a vehicle is established within five minutes of seeing the vehicle.

2.1 Just-in-Time Manufacturing

As the customer's demands evolved outside of the assembly plant, so too did strategies within the assembly plant. One major shift of the early 90s was the implementation of just-in-time (JIT) delivery. Roughly defined, JIT manufacturing allows automakers to reduce inventory holding costs by requesting a smaller batch size delivery schedule from suppliers, while suppliers either hold the inventory at their own facilities, or produce to a more immediate demand schedule. This move dramatically reduced inventory levels at assembly plants from multiple weeks of inventory to multiple hours of inventory.

However, smaller lot sizes require more deliveries for the same production schedule. As one report commented on the industry trend, "Assembly plants could shorten production runs on some components. The smaller number of parts available in inventory meant that they had to monitor run-to-run variation in part quality more closely than before."[2] An increased delivery per shift increases the potential for lot-to-lot variation as well as run-to-run variation. While the advantages to JIT delivery are clear, so is the need for process control around variation reduction.

2.2 The Lexus Ball Bearing Commercial

Many automotive experts point to a single Lexus commercial in 1992 as the impetus for customers to demand high quality, precision vehicles. Part of Lexus's "Relentless pursuit of excellence" campaign, this commercial showed a steel ball rolling smoothly down the precisely-tuned and parallel panels of a Lexus ES300. The demonstration showed viewers that quality can be "perceived" by watching a ball flow smoothly down the body panels. The commercial said "At Lexus, not we achieved extremely tight tolerances between all major body parts. Not only does the ES300 look like it's put together well. It is put together well."[3]

In September 2003, a team of researchers from MIT published a report analyzing the trend for tighter tolerances through process control. They also mentioned this impact of this commercial:

> In the early 1990s, a Lexus television commercial made engineering precision an overnight star by demonstrating that a steel ball could roll smoothly down perfectly flush gaps along the panels of the company's flagship sedan. The advertisement, with its dramatic focus on quality, was widely noted in the United States, but it would not have merited as much attention had it aired before a European or Japanese audience.[4]

The commercial certainly merited the attention of American consumers and automakers. Companies began making their own versions of this commercial. Nissan created and aired a commercial wherein it claimed that the Nissan Altima possessed gaps as tight as the Lexus ES300. BMW followed suit. Even Roy Rogers sandwich shops had their own version. PBS performed a study on this commercial and reported the following:

> After Lexus made the ball bearing famous by rolling it seductively over the precision engineered lines of its luxury sedan, Nissan did the same thing in their ad to demonstrate how a much less expensive car could exhibit the same qualities. BMW sought to rise above the whole affair, demonstrating their car's unmatched turning radius by putting the whole vehicle through the same tight turns as the ball bearing went through in the other brands' meaningless test. Finally, in an irreverent spoof of the automobile advertising wars, Roy Rogers rolled a ball bearing around the edge of a roast beef sandwich.[5]

2.3 The 2mm Project

The advances in dimensional control demonstrated by the Japanese demanded that American automakers react. Automakers recognized that dimensional variation produced inferior product, wasted material, and increased production time, which all led to lost market share.[6]

In 1991, the Americans auto industry responded to such pushes in perceived quality and the "pursuit of excellence" with the "2 Millimeter Project" hereafter referred to as the 2mm Project. A consortium of companies partnered in this effort to make American Automakers more competitive, including General Motors, Ford, the University of Michigan, and Wayne State University. The program lasted from 1992 to 1995. It was funded through the Advanced Technology Program (under the auspices of the National Institute of Standards and Technology (NIST)), with the intent to develop technologies and processes that would improve the overall quality, help automakers understand process control, and lower production costs of American vehicles. [7] The ultimate goal was world-class vehicles through manufacturing and assembly improvements. As one report summarized, "The successful realization of these objectives would have a direct impact on the ability of the U.S. industry to remain competitive and in accordance with prevailing world quality standards."[8]

The 2mm Project is so-named because 2mm represents the upper limit for panel gap variation that American automakers desired. Variation in gap width between moveable panels is challenging to control (moveable panels includes doors, trunk, hood, etc). Since the build of a vehicle is a complex and integrated system, variation in panel gaps can have a domino effect in the build of a vehicle. This domino effect is analogous to tolerance stack-up, wherein final dimensions of a system can be multiplied far beyond their specification limits due to the accumulation of variance in the system's parts. For example, a gap between the front fender to front door will affect the gap between the front door and rear door, which will affect the gap between the rear door and the rear fender. As a group of researchers noted:

> Just a few millimeters make a big difference on an automated assembly line as doors, hood, windshield, wheel housings, and other parts are installed on a body-in-white (BIW), the partially completed body of an automobile. ("BIW" refers to the vehicle body as it proceeds through the assembly line prior to being painted.) If BIW openings are slightly off kilter or parts vary much from specifications, the overall fit and finish of the completed car suffers. When dimensions vary more radically, a BIW may have to be re-worked by hand. In addition, if the variations grow too large, the entire BIW may be pulled from the assembly line and junked. In contrast, a tightly fitted car means fewer defects, faster assembly times for parts and components added later in the process, less time and money for factory repairs, better appearance and performance for the owner, and lower long-term maintenance costs.[9]

By the late 1980s, the Japanese automakers boasted dimensional variation of 2.0 mm or less, with the Europeans close behind at 2.5mm. The Americans lagged behind with gaps variation at 7mm. In a market where car buyers consider fit and finish as major purchase factors, lower variation in gap panel to panel gaps was becoming a competitive advantage.[10]

2.3.1 The Advanced Technology Program

A representative from NIST described the origins and approach of the Advanced Technology Program (ATP) in the following speech:

> An Advanced Technology Program project has focused on the assembly side of things. The prospect of an ATP award was the impetus for forming a not-so-likely cast of partners: eight suppliers of assembly equipment and engineering services, two universities, Chrysler and General Motors. The effort was called the "2-millimeter project," which referred to the goal of pushing beyond the then world-class standard for dimensional control in automobile bodies. (Another goal was to be able to roll a ball bearing down the seams of a U.S. built car the way it was done in the Lexus commercial a few years ago.) The research strategy was to take a coordinated systems approach--to identify and model the factors that contribute to dimensional variation and, then, to devise a metrology-based assembly process.

The ATP supported the 2mm project throughout its three year lifespan, and invested \$4.4 million. The participating firms contributed \$5.1million, and the American vehicle manufactures contributed \$115 million for equipment and systems.[11]

2.3.2 An Analysis of the ATP 2mm Project

As mentioned before, a team of outside researchers also evaluated the effectiveness of the 2mm project in a report to the National Institute of Standards and Technology. The research was composed of mechanical engineers, economists, and planners from MIT, the Harvard Business School, and Case Western Reserve University. Their findings significantly relate to the work performed by the author at the Automaker, and will be discussed in this section.

The researchers concluded that the following gains were realized by American automakers through the 2mm project[12] (the list contains direct excerpts from the 2003 report):

- Reduced variation in vehicle body gaps to 2.5-3.0 mm
- Was the key driving force in changing the manufacturing quality control technology used by domestically owned vehicle manufacturers
    - Both GM and DaimlerChrysler established new procedures for identifying the underlying sources of variation in vehicle body manufacturing.
    - Plant personnel learned how real-time data could be used to diagnose and correct the multitude of problems that underlie dimensional variation.
    - Manufacturers experienced reductions in scrap costs (which initially had resulted from manufacturing errors) ranging from $1 to $3 per vehicle
    - All GM plants … are now implementing analytical software developed during the research phase of 2mm…but setting the stage for possible improvements in vehicle design and manufacture as new models are developed.
- Manufacturers noted reductions in rework/repair expenditures of approximately $3 per vehicle and anticipated reductions in warranty claims (although none had explicitly analyzed such impacts).
- Assembly-line integrators (firms that supply the tools used to form a vehicle assembly-line) gained improved understanding of how assembly tools can cause

> dimensional variation and have undertaken the adoption of new tool-mounted measurement technologies to gain improved control over tool-induced variation.

A more technical list from the researcher's report is included in Appendix A.

In summation, the researchers determined that the 2mm project was the "key driving force" in revolutionizing quality control for American automakers. However, they concluded, "...our model results indicate that the gains in market shares are transitory, in that share growth continues as long as quality improves, but does not grow perpetually. After the quality improvement is recognized in the market, shares eventually stabilize at their new level."

To continue to regain market share, continuous improvement is imperative. Once world-class standards are achieved, further improvements must be pursued continuously. However, improvement beyond world class comes slowly. As the 2mm Project research team concluded:

> For shares to grow further, a pattern of continuous improvement is required, but this feature is not uniformly evident in the plants of domestic manufacturers. The world-class standard that was 2mm at the start of the ATP project continues to improve, but it remains one set by foreign competitors and not by domestic manufacturers, who appear to have reached a plateau (one, nevertheless, made possible by the 2mm technology.)[13]

3.0 FUNDAMENTALS OF PROCESS CONTROL

3.1 Definition

Process Control represents a fundamental aspect of quality engineering. Many other tools may incorporate some methodology of process control in order to engineer quality, such as design for six sigma, lean engineering, statistical process control, design for manufacturability, and total quality management. The aim of each of these is the "systematic reduction of variability in the key quality characteristics of the product."[14]

For the purpose of this thesis, the term "process control" is defined as the measures which are defined to keep a process within tolerable limits, as well as the reaction plan associated with a discrepancy.

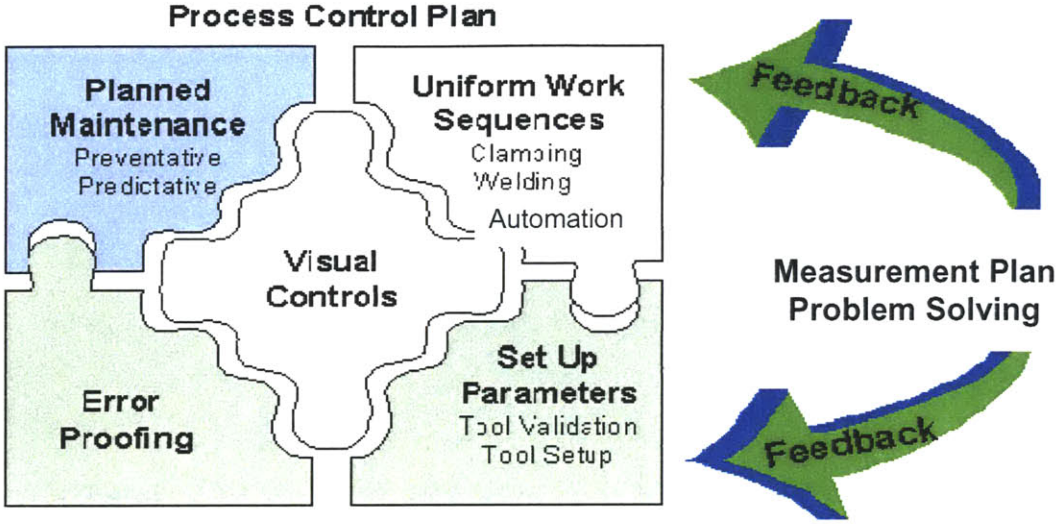
3.2 Key Components

Process control plans generally consist of five key steps:

1) Define the process and owners
2) Define the upper and lower control limits
3) Utilize statistical techniques to interpret trends (generally six sigma)
4) Set alarm limits with varying degrees of severity
5) Define the reaction plan and owners

A pictorial representation of these steps as they relate to an automotive body shop is displayed in Figure 1. As this thesis is focused on project-based research within an automotive body shop, Figure 1 is particularly applicable to body-in-white assembly.

Figure 1. Key Components of a Process Control Plan



The graphic, adapted from a major automaker's procedure for control, depicts the basic elements of a process control plan. A solid process control plan must contain the four puzzle pieces of body shop control, integrated by a central focus on visual control. The pieces are:

1. **Planned Maintenance** (also referred to as Preventative Maintenance)
2. **Standardized Work**
3. **Parameter Identification** (i.e. allowable operating domain with upper and lower control limits)
4. **Error Proofing**

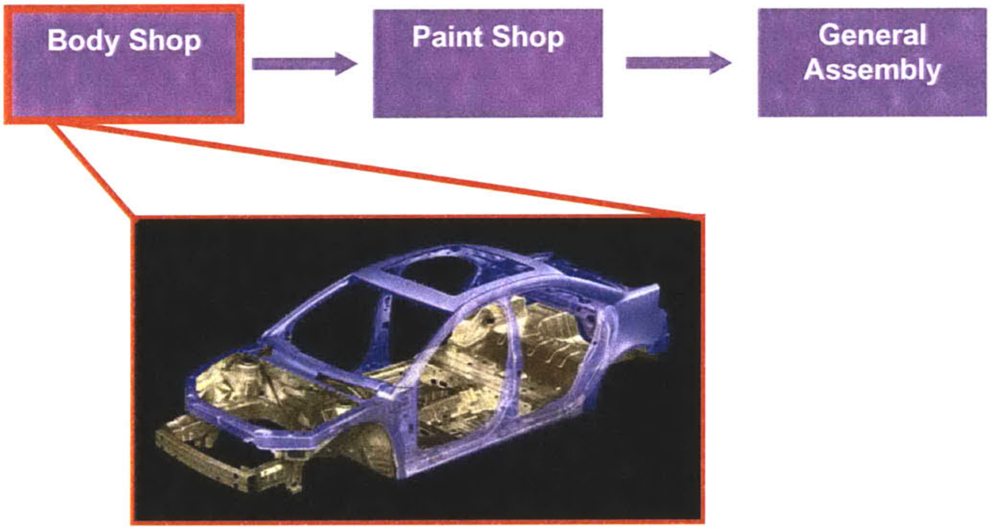
The figure also highlights the need for a continual feedback loop to aid in problem solving and continuous improvement of the measurement plan. A fifth puzzle piece, however, should be included when the diagram is applied to dimensional control. Part variation reduction and control is a key component of designing a proactive and rigorous control strategy.

One element missing from the diagram is a part variation control. Specifically for a solid dimensional process control

3.3 Process Controls in an Automotive Body Shop

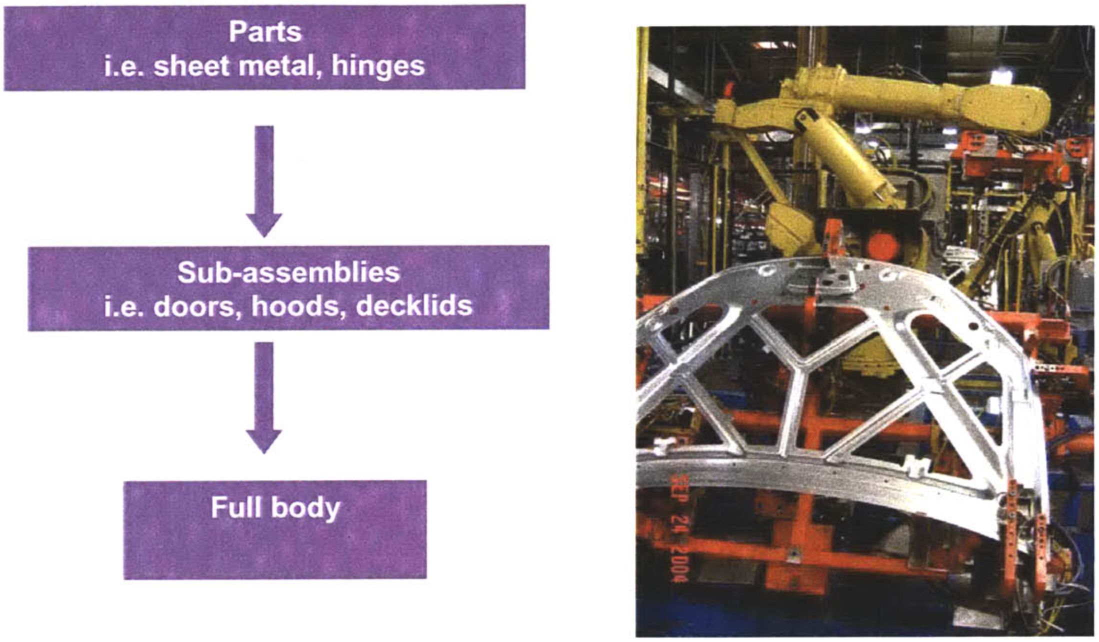
The body shop is the first step in the assembly process, as show in Figure 2. The paint shop, general assembly, and the final process line are the downstream customers of the body shop.

Figure 2. Overview of Vehicle Assembly Process



Process control in a body shop is crucial, as this operation is the foundation for the vehicle build. The dimensional integrity of the body is determined by the process controls present as each piece of sheet metal is welded together. As depicted in Figure 3, an automotive body is often assembled in a "layered build" fashion, where individual pieces are loosely assembled with metal tabs (often called "toy tabs"), welded together into subassemblies, and the sub-assemblies are set dimensionally and welded together to produce the vehicle's skeleton. The passenger car assembled at the author's thesis site contained over 2900 welds.

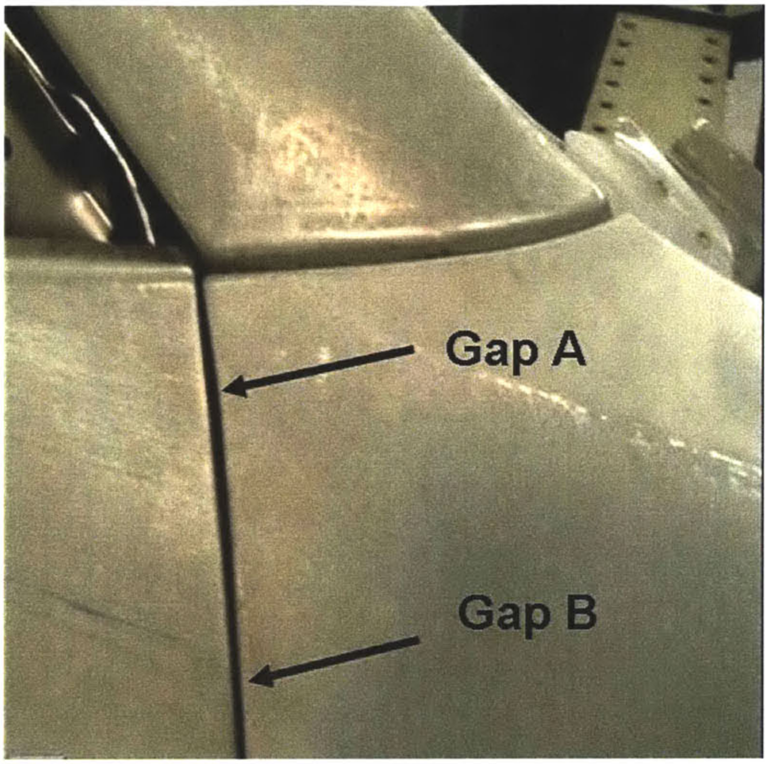
Figure 3. Overview of the Layered Build Process



Hood Subassembly

As previously stated, the rigor of process control in the body shop determines the dimensional integrity of the vehicle. If the critical process characteristics fail to meet specification, general assembly will experience difficulty in assembling customer-facing features or otherwise (i.e. headlamps and bumpers). Figure 4 shows an example of poor sheet metal fits at the a-pillar, front door and front fender.

Figure 4: Example of Poor Sheet Metal Fit



The poor sheet metal fit is evident Gap A is larger than Gap B. This difference is quite small, perhaps one or two millimeters. However, even small differentials are of concern to automakers. This type of poor fit would require rework before the car leaves the assembly plant. These fit and finish characteristics can affect a customer's perception of quality.

Beyond aesthetic fit and finish, dimensional integrity can affect the vehicle's and closure system function (door and decklid opening and closing efforts). JD Power and Associates surveys customers on many of these factors. Therefore, high performance in each is paramount for vehicle sales.

These global objectives can be applied locally as more succinct, defined objectives for body shop process controls:

- Contain discrepancies within the body shop, such that zero defects are shipped to the paint shop
- Limit rework downstream
- Provide data for problem solving and root cause analysis

3.4 "Soft" Elements

Process controls seem inherently black and white, based on rigid parameters, statistical analysis, and defined reaction plans. However, the elements of a solid dimensional control strategy will crumble if the softer, organizational, and cultural aspects are ignored by the dimensional team leadership and/or members. Although a cultural analysis will be provided in Chapter 5, it is worth mentioning the softer elements which must be incorporated into a dimensional team's control strategy. Each of these elements will be evaluated further, and examples of how to implement each of these softer elements will be provided.

1. **Communication**
    a. Regular dimensional quality team meetings
    b. Visual communication on floor
    c. Single Point of contact for process changes
    d. Feedback loops from downstream customers and systems

2. **Documentation**
    a. Record process changes
    b. Keep it visual

3. **Quality focus**
    a. Engage every employee
    b. Coach and teach employees so that they fully understand. This knowledge is much more powerful than just directing them to do things.

4. **Empowerment**
    a. All team members are empowered to stop the line for defects

5. **Team Engagement – Salaried, Production, and Skilled Trades**
    a. Performance incentives based on quality

Throughout the author's analysis of five automotive assembly plants, these five "softer" elements of control were pronounced in the more successful body shops. Body shops that embraced the elements were among the most cohesive, agile, and disciplined teams that the author examined. Furthermore, the dimensional team members expressed greater satisfaction in the body shop working environment.

These elements are often neglected due to the prevalent reactive mentality in assembly plants. Therefore, incorporating solid communication, documentation, and a rigorous quality focus among all team members is perhaps the most challenging aspect of maintaining a solid dimensional control strategy.

4.0 ORGANIZATIONAL CHANGE ANALYSIS

4.1 Strategic Lens Analysis

The process control initiative is one that springs from the overarching desire to improve both perceived and actual vehicle quality. As an outsider to the Automaker and without having access to the highest executive leadership, it is difficult to assess or even define the driving strategy embraced by the Automaker. Perhaps the observation that it is difficult for a trench-level worker to define the quality strategy is symptomatic of an underlying strategic issue.

4.1.1 Quality Policy

Since process control stems from an overarching desire for quality improvement, it is reasonable to ask "What does quality mean to each employee of the automaker?" In "What Does 'Product Quality" Really Mean?," David Garvin explains that multiple approaches and definitions of quality exist. For a firm to compete on quality, it need not compete on all eight dimensions, but must define which segments it wishes to target. The eight primary dimensions of quality are as follows[15]:

1. Performance
2. Features
3. Reliability
4. Conformance
5. Durability
6. Serviceability
7. Aesthetics
8. Perceived quality

It is evident by these eight dimensions that quality will not be thought of through the same lens for all employees within an organization. Employees within an organization might view quality through different lenses, perhaps based on his role or function. For example, a maintenance person might think of quality differently from a production employee based on his own definition of quality, by how his performance score card measures quality, or by his own approach to his work.

It is important for an automaker to possess a policy which is transparent, emphasized consistently and engrained in the corporate culture. Quality must be clearly defined for each employee. Management must focus on teaching the quality policy to employees, and must reinforce the policy by rewarding those who abide by it. Management must teach, coach, and empower employees regarding *how* to implement quality measures in each person's every-day job.

4.1.2.2 Ownership of the Initiative

The process control implementation project was assigned to the author by the manager of the plant's problem solving group. The manager of this group was keenly aware of the opportunity for improved process control in the body shop. However, his group was designed to provide a supporting role to body shop production and engineering activities. Therefore, his group was not empowered to lead a process control initiative. The problem solving group does not own either dimensional process control or weld process control. This misalignment could be minor, if the true owners of the problem are willing to recognize the need for process control and champion the solution.

The Weld Coordinator, who owned the welding process control plans, fully supported the initiative, however his time was consumed by reacting to issues on the plant floor, and spent little time implementing process control plans. He was willing to work large amounts of unpaid overtime, therefore, the bulk of the control plans produced by the weld coordinator and author were produced after working hours.

Each of the groups mentioned in this section are key to enforcing process control philosophy in the body shop organization. The problem solving group, the dimensional coordinator, and the welding coordinator, as well as upper management must coach, teach, and empower employees to be proactive in problem solving and corrective action. These stakeholders must teach employees that acting proactively will save time in the long run, though it may appear to be a large upfront investment. Furthermore, management must empower employees to act in the interest of rigorous process control. By driving the decision power to the lowest possible level on the plant floor, measures can be taken efficiently, effectively, and continuously while maintaining the integrity of the decision.

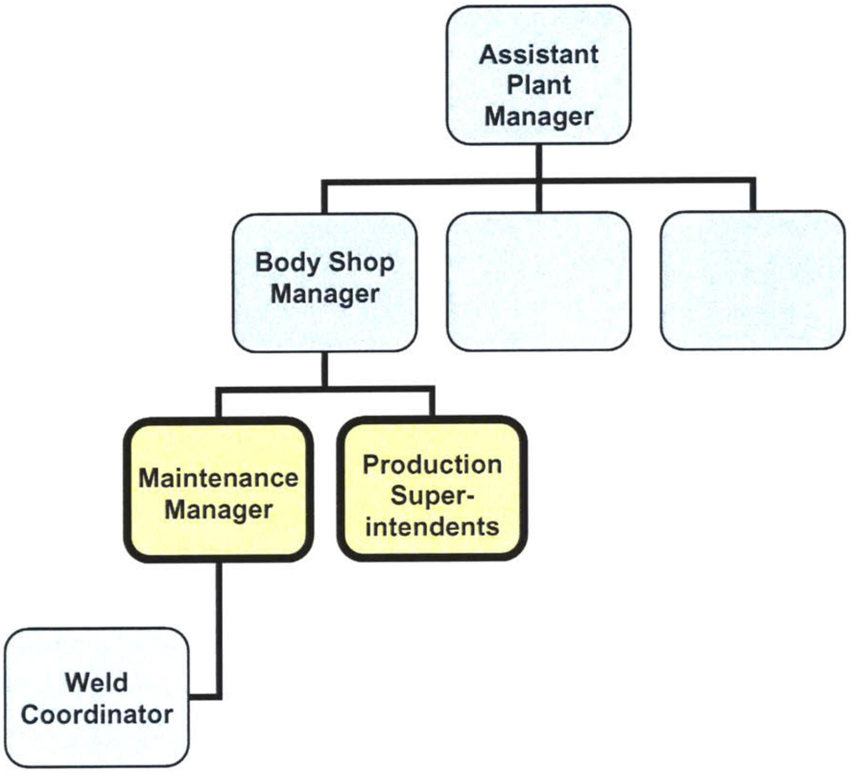
4.1.2.3 Process Control Managers

Each assembly plant within the Automaker possessed a Process Control Group, falling under the Plant Quality Manager. The job descriptions of each process control manager varied widely from plant-to-plant. At the plants that the author benchmarked, some Process Control Managers (PCM) were highly engaged in statistical process control, visual management, and the other tools discussed in this thesis. However, at the author's plant, the PCM's tasks primarily involved daily reporting of plant production and defects in the body shop and defects at the final line due to body shop. He was also engaged in creating visual aids. However, his involvement with the process control initiative in dimensional or welding quality was virtually nonexistent. This organizational design aspect seemed to be misaligned, as the PCM job description in the body shop involved primarily reporting rather than preventing. His manager, the Quality Manager, was directly involved with the process control initiative.

4.1.2.4 Battle of Quality vs. Throughput

A final misalignment of organizational strategy and the process control initiative existed via the battle of quality versus throughput. Both the body shop Maintenance and the Production organization reside organizationally under the Body Shop Manager, as depicted in Figure 5.

Figure 5. Body Shop Maintenance and Production Reporting Structure



The battle between quality and quantity is not unique to the automotive assembly environment. As Montgomery writes in Introduction to Process Control, most manufacturing businesses of today's modern industrial environment face the quality versus productivity dilemma. He writes, "Often, too little attention is paid to achieving all dimensions of an optimal process: economy, efficiency, productivity, and quality. Effective quality improvements can be instrumental in increasing productivity and reducing cost."[16]

Oftentimes this battle is cultural and may be diminished through properly aligned incentives. However, a misalignment of incentives existed between the production and the maintenance organization. Production is evaluated based on quality, or the number of defects caused by the Body shop. However, they too cope with the throughput versus quality dilemma, and are often "in trouble" if they fail to meet the daily throughput requirements. In interviewing employees regarding what they believed was the strongest incentive for the production and maintenance organizations, the author found that many employees were not aware that both production and maintenance are scored on quality *and* throughput. Indeed, it is critical that an automaker balance these two aspects of production, and aligning incentives towards the goal is imperative. The author found that even if performance reviews list metrics of throughput and quality, it may be unclear to the plant floor which is most important. Management's actions and decisions must reinforce that quality is the priority.

One area where empowerment towards process control activity lacked was within the maintenance organization. As shown in Figure 5, the welding organization falls under maintenance. The weld coordinator possessed the authority to implement weld monitoring process control, however, he was evaluated by his superiors on the basis of how quickly discrepancies were repaired and shipped out of the door. Though he desired improved weld monitoring process, he rarely found time to perform root-cause analysis and implement preventative measures to avoid future discrepancies.

In a fast-paced, intense environment such as an assembly plant, it is natural for an employee to feel that a pro-active approach to process control requires more time than he or she has to invest. However, management must educate employees with the understanding that pro-active measure will actually save time for the person. An "I don't have time" attitude is not acceptable.

As show in Figure 5, maintenance and production run the body shop. Therefore, it is critical that their incentives be aligned in order to work as a partnership. Clearly, these incentives need to focus on quality rather than quantity.

4.1.2 Pull for the Initiative

Very little pull existed at the grass roots level for this initiative, primarily due to strategic design and culture. Ultimately, the major enabler to process control improvement was the Assistant Plant Manager's observation of the potential to reduce waste through process control, and forcing the organization to act accordingly.

The Assistant Plant Manager's (APM) involvement was critical to pushing the initiative. With his watch-dogging, the weekly process control meetings were taken seriously, and major deliverables and timing were adhered to. Dimensional integrity and weld control were his top priorities. He also recognized the need to create a visual structure around the body shop process controls, so that the process was clear to all stakeholders and could be communicated without digging through reams of data or paperwork. He told the newly-formed process control community, "I want this to be the #1 priority in the Body shop, behind safety." The APM utilized the author as an unbiased representative of the process control team. Therefore, the author's responsibilities evolved into pushing issues with the dimensional and weld community, and providing the APM with feedback of the team's progress.

Strategically, involvement by the plant management was critical to getting this initiative up and running. Unfortunately, the job design or the way the jobs of key players has evolved (such as the Dimensional Manager and the Process Control Manager) lacked emphasis of process control, and many aspects of the plant's culture, including the reactive, counteract the preventative nature of process control. Clearly, this culture can be changed if management continues to emphasize the dividends of investing in process control. These benefits include making it easier to achieve quality and quantity.

4.1.3 Coordinating Systems for the Initiative

Prior to the author's internship, the coordinating systems for the process control initiative were weak. Ultimately, several systems were implemented by the end of the author's internship in order to support the initiative. These systems will be discussed further in Chapter 5. They are as follows:

1. Weekly Process Control meetings, often attended by the Assistant Plant Manager
2. Published action item log for each process control initiative (i.e. welding, dimensional, etc.)
3. Layered audit system across the plant, for all levels of employees
4. A revamped and formalized weld monitoring process
5. Visual Management of items 2, 3 and 4.
6. Training class for applicable Body shop team members regarding the refined weld monitoring process.

Each of these items requires discipline and continuous improvement. However, support from the top coupled with watch dogs within the body shop and layered audits provide a support network to keep these systems thriving.

4.2 Political Lens Analysis

4.2.1 Stakeholders

The direct stakeholders for process control implementation during the launch of a new vehicle primarily reside in the plant. Table 1 lists each of the stakeholders and their role as it relates to process controls. It is important to note how each stakeholder expressed interest in the initiative to implement and improve process control plans in the body shop, and to note whether these interests of the stakeholders are compatible. The "++, +, 0, and - " symbolism represents the degree to which the stakeholder expressed interest in the initiative, where a "+" represents strong interest, a "0" represents indifference or no expressed interest, and a "-" represents disinterest or opposition.

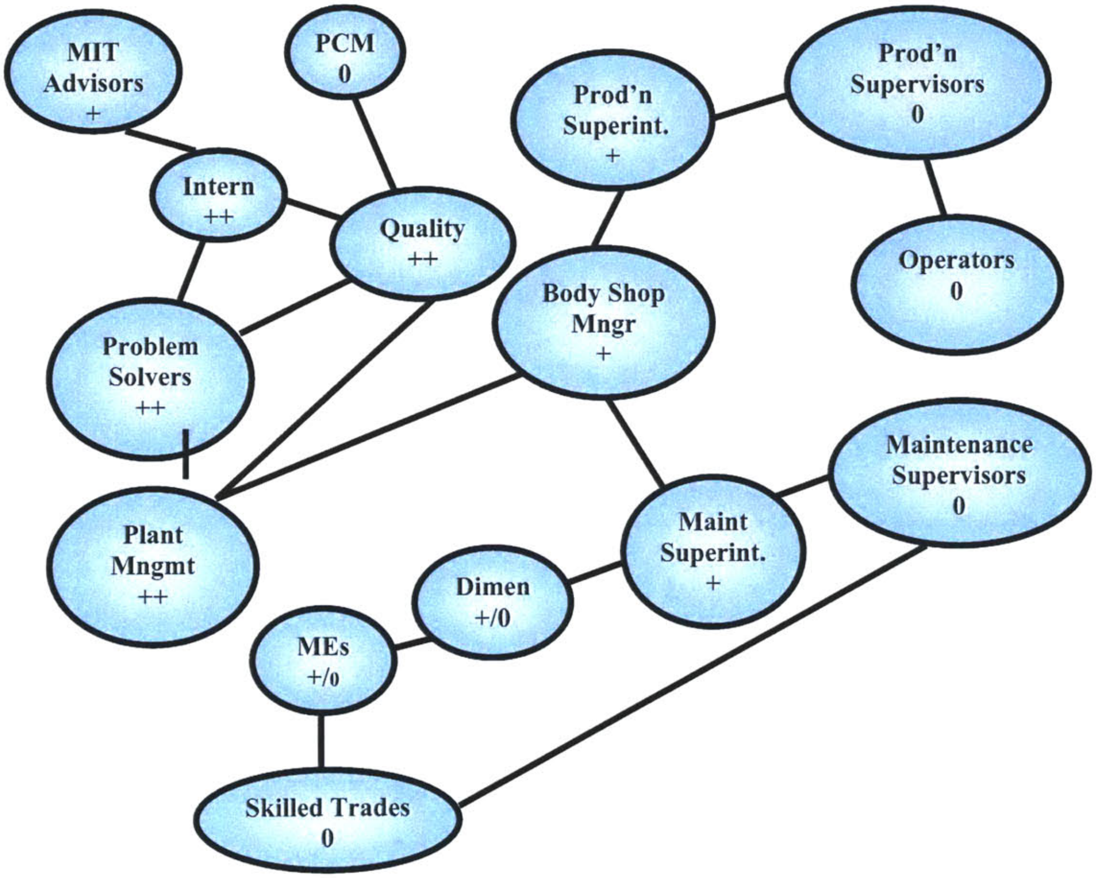
Table 1: Stakeholders Interest in Process Control Initiative

Stakeholder	**Role Relative to Process Control**	***Expressed* Interest in Process Control**
Engineering Problem Solving Group	Liaison between production and engineering for problem solving tasks	++
Quality Group	Production quality concerns	++
Process Control Manager (PCM)	Ideally, this role is intended to be the champion of process control implementation in the body shop. In practice, the extent to which this person leads the initiative varies drastically.	**0**
Body Shop Production Superintendents (Prod'n Superint.)	Daily operation of body shop; accountable for defects leaving body shop	+
Dimensional Group (Dimen)	Responsible for dimensional integrity of build, data review and corrective action.	+/**0**
Body Shop Manager	Authority over Maintenance and Production. Responsible for quality and throughput of body shop.	++
Plant Management	Plant Manager and Assistant Plant Manager	++

Production Supervisors (Prod'n Supervisors)	First-line supervision of operators	**0**
Maintenance Superintendents	Authority over Maintenance Supervisors. Responsible for machinery and facilities, support to production	**+**
Maintenance Supervisors	Responsible for maintenance skilled trades; repair of machinery and support to production operations	**0**
Manufacturing Engineers (MEs)	Production support for engineering issues affecting quality or throughput	**+/0**
Skilled Trades	Support for maintenance and dimensional engineering	**0**
Operators	Production	**0**

Figure 6 shows a stakeholder map. The stakeholder map shows how the players are interrelated, and how their interests in process control are aligned.

Figure 6. Stakeholder Map



Generally speaking, implementing solid process control plans and improving upon current control plans is in every stakeholder's best interest. Therefore, stakeholder interests are aligned. However, the development of PCPs is time-consuming. For those stakeholders who are incentivized strongly towards other ends, the development of process control plans may not be a priority.

Therefore, upper management support of the process control initiative is a necessity. Polenske and researchers noted a similar need for upper management to push issues down even when the benefits are readily apparent. Regarding the 2mm Project, Polenske writes:

> The program demonstrated to its participants, and to their nonparticipating customers, that the technology works and can generate quality and productivity improvements quickly and potentially at low cost. The transformation of the industry, however, is tied to the "buy-in" of top management at the OEMs and the speed at which new equipment and trained personnel are moved into plants, with adoption being timed to new assembly-line installations and not necessarily the speed needed to meet competitive pressures.[17]

The process control initiative at the assembly plant took a major turn when the Assistant Plant Manager pushed the issue. Stakeholder interests which were not completely aligned initially were "forced" to be.

This dependence on a single person to push the intiative, however, is risky. Though it is important that top management motivate employees to action, the body shop community must embrace process controls on their own. Therefore, the initiative will not be threatened if one leader leaves the plant or is unable to patrol the implementation.

It is possible to avoid forcing initiatives, however, by better aligning incentives. If each of the key stakeholders is accountable for process control related items, then stakeholder interest will turn towards process control. These items could range from number of quality defects at a verification station to the regular review of data followed by root cause analysis, or amount of time spent on preventative measures versus amount of time spent reacting.

4.3 Cultural Lens Analysis

4.3.1 Approach to Problem Solving

Clearly, the reactive mentality is a dominant cultural barrier to implementing a preventative process control initiative. Though most team members understand the benefits of process control, cultural barriers can inhibit the implementation of proactive control strategy. Furthermore, the engineers at the Automaker were highly skilled at solving problems quickly. Careers may be built on a person's success at doing so. The people who were able to solve problems quickly and effectively were well-known throughout the plant. The Automaker possessed a very strong problem-solving methodology, which is a necessary component of building quality vehicles efficiently. However, rewards and recognition favored reactive behavior rather than proactive process control methodology. Therefore, operating with a solid process control strategy in order to prevent issues, rather than react and solve issues, is a significant culture shift.

4.3.2 Labor-Management Relations

In general, union employees and skilled tradespeople embrace process control when they see the ultimate goal of the activities. Historically, labor relations are not severely disrupted by such initiatives. For example, the 2mm Project of the 1990s introduced a type of process control initiative on a much larger scale. Researchers commented on the 2mm Project's affect on labor-management relations:

> In some plants, personnel greeted the new technology with enthusiasm, viewing it as an opportunity to work with advanced technology and computer systems and gain access to potentially higher long-term wage-earnings growth and greater job security. Labor thus viewed the evolution to 2mm technology as being consistent with union efforts to promote job "upskilling."[18]

Similarly, the author observed many people on the plant floor who were supportive of process control. Though many employees brought negative paradigms regarding process control based on their experience at other facilities, there were also many people who possessed a positive work ethic regarding control implementation. Part of the challenge by the process control team was to motivate all employees to be interested in process control implementation.

Many production employees do desire to improve the manufacturing environment, and this is promoted through a strong employee suggestion program. Over 90% of employees at the assembly plant participated in this formal suggestion program.

Finally, the plant management was extremely supportive of the operator. The Plant Manager urged engineers and managers to act with urgency and pride in order to support the operator. The Plant Manager could often be observed trying operations on the line for ergonomics, and was well-respected by the majority of the plant's operators. This type of partnership with factory workers is critical also to process control implementation. Engineers must show their concern and respect for the worker as process control are designed and implemented. Only then can engineers receive full support and cooperation from the operators.

5.0 LEAN PROCESS CONTROL IMPLEMENTATION

An automotive body shop is a complex operation. At any given second of production, hundreds of processes are executed. Sheet metal is assembled, panels are welded, data is gathered, repairs are made, machines are maintained, waste is discarded, stock is replenished, quality is examined, machinery is adjusted, welds are tested, and dimensions are measured. Opportunity for process control exists at every corner.

The author's target area for process control implementation was the weld monitoring process of the body shop. The following chapter will examine what process control measures were developed and implemented to create a leaner weld monitoring process. Numerous steps within the weld monitoring process were streamlined and supporting documentation was created. However, the bulk of the technical content and documentation is confidential to the Automaker, and will not be included in this thesis.

5.1 Lean Production Systems

The approach taken to analyzing the Automaker's weld monitoring process was based on lean principles. The Automaker possessed a lean manufacturing strategy similar to the Toyota Production System (TPS). The manufacturing strategy consisted of five basic tenets:

1. **Standardization**
2. **Short Lead Time**
3. **People Involvement**
4. **Built-in-Quality**
5. **Continuous Improvement**

This lean strategy was implemented to varying degrees at all of the Automaker's assembly plants. Therefore, a framework existed within the organization and culture which enabled the author to lead an effective analysis of the existing weld monitoring strategy. These principles, along with a few other principles of Lean Engineering, highlight the changes made to the weld monitoring process at the Automaker. This thesis will specifically focus on items Standardization, People Involvement, Built-in-quality, and Continuous Improvement.

5.2 Explanation of Weld Monitoring Process

The weld monitoring process refers to the inspection of 100 percent of a vehicle's welds four times per shift. A typical number of welds for the type of vehicle produced at the assembly plant is roughly 3000 welds. These welds are tested and inspected by weld monitors. The weld monitors are skilled tradesmen who are certified in weld inspection and destruction.

Since the Automaker's internal requirements dictated that each weld be checked four times a shift, weld monitors were required to check 12,000 welds per shift, as well as communicate nonconforming welds for corrective action to be taken. Therefore, the inspection of welds was a full-time responsibility which employed at least two or more weld monitors per shift. The number of weld monitors employed varied plant to plant, based on production schedules, variety of build architecture, etc.

5.2.1 Types of Inspection

Figure 7 shows a weld monitor performing a chisel check. Chisel checks are performed on welds that are accessible to hand-held tools. The picture on the left shows welds being chiseled, and the picture on the right shows the tools used to perform the test.

Figure 7. Chisel Check Performed on Welds

Most chisel checks, like those in Figure 7, are nondestructive. "Nondestructive" indicates that the part does not need to be scrapped. Often, chisel checks are destructive, such as those performed on doors. Figure 8 shows a door which has been destructively tested and must be scrapped.

Figure 8. Destructive Weld Test

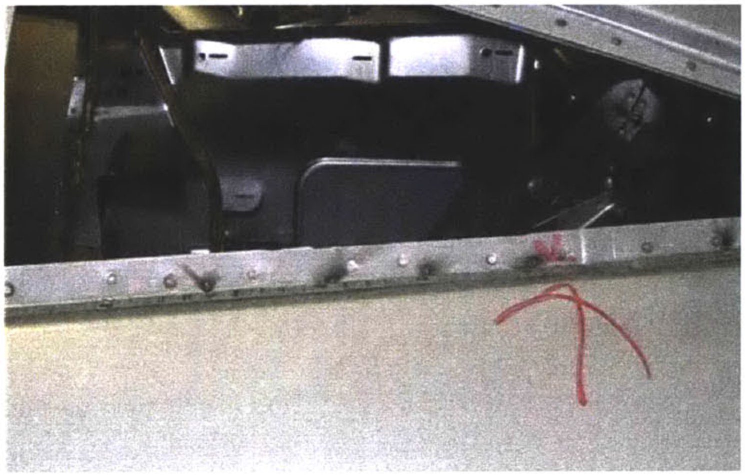
Along with chisel checks, weld monitors performed visual inspection of welds and weld studs, toggle locks, and sealant applications. Figure 9 provides an example a discrepancy called "burn through" that was detected visually. The weld burned through the sheet metal, allowing the weld stud to break away from the material.

Figure 9. Weld Stud Burn Through

5.2.2 Nonconformance Identification

When a weld monitor detects a nonconforming weld, he or she must mark the weld and notify the proper authorities. Figure 10 shows an edge weld (a weld that is too close to the edge of the sheet metal) which a weld monitor has marked.

Figure 10. Identified Nonconforming Weld



The marks (arrows) on the vehicle panel are the marks that the weld monitor drew on the sheet metal. Further explanation of the nonconformance reporting and reaction plan will be discussed later in this chapter.

5.2.3 Challenge to Process Control Team

The core weld monitoring process control team consisted of the author, the weld coordinator (who supervises the weld monitors), the maintenance superintendents, and the union committee man. The challenge to the process control team was to evaluate the current weld monitoring process and make the appropriate improvements. In order to truly understand the weld monitoring process, the team focused on understanding the life of a weld monitor and the processes related to weld monitoring. The team interviewed and shadowed the weld monitors for several weeks, responded to nonconformance alerts to evaluate the reaction plans, and researched corporate and legal documentation related to weld mentoring standards.

The team found several areas where enhancements could be made. The primary areas that will be discussed in this thesis are as follows:

1. **Efficient documentation:**
    a. Efficient Inspections
    b. Corrective action taken
    c. Sign-off of relevant parties
2. **Feedback loop timing improvements:**
    a. Time to document a nonconformance
    b. Time to notify relevant parties of nonconformance
    c. Time to implement corrective action, thereby reducing the number of parts requiring repair
3. **Pre-defined reaction plans**
4. **Safe and effective weld monitoring stations and equipment**
5. **Clear communication of the above items**

The following section will discuss how lean principles were applied to process control strategy and guided the improvement of the five areas listed above.

5.3 Standardization

The term standardization can refer to many aspects of the workplace, including job instructions, operating procedures, and visual aids. The Toyota Production System manual states, "Standardized work provides a consistent basis for maintaining productivity, quality, and safety at high levels."[19] The process control team also employed standardization to improve productivity, quality, and safety. Visual management and standardized documentation were implemented on several fronts to improve the efficiency of the weld monitoring process.

5.3.1 Visual Management

Visual management is a simple strategy, yet offers a large payoff for a relatively small investment. When implemented effectively, visual management provides workplace awareness to all levels of employees as well as worker empowerment and continuous improvement.

Similar conclusions were drawn by Brett Balazs, Leaders for Manufacturing Fellow '04, on his internship at Raytheon. In his analysis of a Ribbon Bonding Process, he discovered that operators were not exposed to meaningful data, and therefore failed to understand the meaning or the necessity for the SPC. By modifying the area's data collection interface, his team was able to provide user-friendly information directly to the operator. Balasz wrote in his thesis, "By making the operators more knowledgeable of the state of the process, it gave them more opportunity to alert both the ribbon bond operator and engineer before any problems persisted." The SPC charts were utilized as a tool for root-cause analysis and continuous improvement.[20]

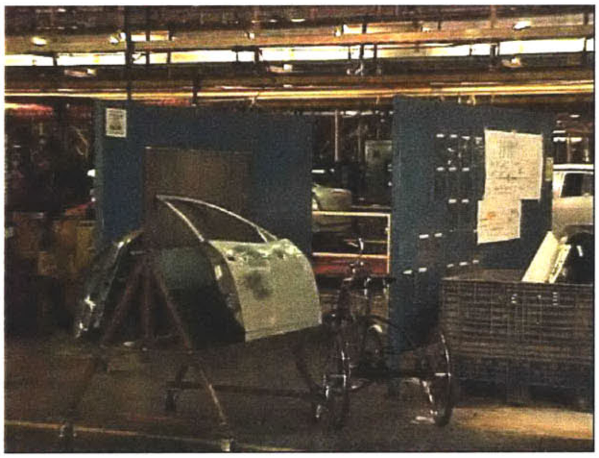
Just as Balasz determined that the workers on the plant floor needed to be exposed to meaningful data, the process control team determined that all level of staff in the body shop should be visually exposed to the weld monitoring processes and documentation.

Prior to the author's internship, the body shop lacked a central area for body shop communications on the floor. Large boards existed on the floor, yet they were not well utilized. They boards were dirty and often overrun by scrap and other equipment.

This area was transformed into the centralized communication area for body shop personnel. Figure 11 shows a before and after photo of this area.

Figure 11. Body Shop Central Control Boards

BEFORE



AFTER

These centralized process control boards became the location where the area manager and superintendents held their production meetings. The outside of the boards held the process control documentation for the weld monitoring process.

5.3.2 Continuous Improvement (Through Visual Management)

Visual management is also a powerful tool to promote continuous improvement. The TPS manual states, "Just as employees need to be versatile in the Toyota Production System, the standardized work itself is flexible and subject to continuing modification and improvement."[21] Balasz observed about Raytheon's visual management, "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."[22] Similarly, those participating in the weld monitoring process used the centralized boards and documentation on the floor to identify strengths and weaknesses of the process. Therefore, the centralized process control boards became a work in progress, and were critical in communicating both the strengths and weaknesses of the process revamping.

5.3.3 Documentation

The centralized process control boards served many purposes. One purpose was to draw attention to items which management wanted to communicate were important. For example, management needed to communicate the importance of a solid weld monitoring process. Thus, management can emphasize the importance of a process by devoting an entire centralized board to it and requiring people of all levels to report at as well as complete documentation contained on the board. Secondly, the boards visually displayed documentation regarding standardized processes and reaction plans, inspection sheets, and log sheets. For the weld monitoring process, the board held the nonconformance log, the nonconformance notice (the document completed when a welding nonconformance was detected), standardized instructions on how to complete these documents, and other pertinent process documentation.

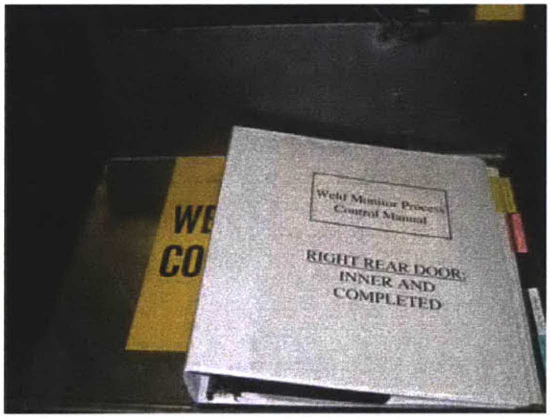
In terms of standardized documentation, the process control team produced several documents which streamlined and standardized the weld monitoring process. The major documents were the following:

1. **Standard weld monitoring inspection sheets:** This form provided a common form for the weld monitors to use at all of the inspection stations across the body shop. Prior to the process control team activity, the weld monitors recorded data via a format that was not consistent from person-to-person or shift-to-shift. A common form provided a standard format for the weld monitors to record inspections at the points of inspection, and allows the weld coordinator or outsiders to quickly understand the weld monitor reports. Please see Appendix B for a generic version of the inspection sheet.
2. **Welding Nonconformance Notice:** This form documents the existence of a nonconformance, and outlines who the weld monitor should contact immediately upon finding the discrepancy. Furthermore, the Nonconformance Notice documented the role of each party in the ensuing corrective action, and required signatures by all owning parties. The form contains five defined steps. See Appendix C for an example of the document, in generic form.
3. **Nonconformance Log:** Located at the central process control boards, the log identified the weld monitoring issues, owners, date of issuance and date of closure, and corrective action taken.

4. **Weld Monitoring Process Control Books:** Approximately twenty process control books were made in total, one for each of the inspection stations (the inspection stations were also a result of the process control team's efforts). Each of the books contained standardized work instructions, the weld monitoring inspection sheets, visual aids of the weld to be inspected at that inspection station, blank nonconformance notices, and technical data regarding the weld properties and metal stack-ups. These books are to be kept at the inspection stations. Each location for the process control books was readily accessible and clearly marked for any staff member to access. Figures 12 and 13 show an example of a shelf in a door assembly station marked for a process control book.

Figure 12. Process Control Manual Shelf

Figure 13. Shelf with Process Control Manual



The process control books were located at the inspection stations. The inspection stations were located directly at the point of production of the parts to be inspected. Under the old weld monitoring system, the documentation that existed (visual aids, nonconformance notices) resided at the weld monitors' desks. Upon finding a discrepant weld under the old system, the weld monitors would walk back to their desks to complete the paperwork. This walk could be up to 10 minutes in length. Then the weld monitors would walk back to the inspected part, doubling the waste incurred through walking time. With all documentation at the point of inspection, weld monitors are able to complete all of the necessary steps immediately, and waste is eliminated from the process.

5.3.4 Common Template and Training

Central engineering at the Automaker organized an effort to create a common template for process control related issues in the body shops of all plants. Though the implementation of this initiative is in its infancy at the time of this thesis, the intent is to commonize the approach to body shop process control across the Automaker, and promote the sharing of best practices by the dimensional managers. The leaders of this initiative have created a website which will require feedback from each dimensional manager, and notify all dimensional managers when feedback is posted by a member of the group. Monthly teleconferences or webcasts will also enable the sharing of lessons learned.

As a further effort at communication at standardization, the body shop process control team formulated a course curriculum to train all staff affected by the weld monitoring process. This curriculum included material related to the following topics:

- Weld monitoring process overview
- Reaction plans to discrepant welds
- Which parties are responsible for which steps of the corrective action and containment efforts

- Introduction to central process control boards
- All supporting documentation and where it resides
- The necessity of weld monitoring process control as related to current societal events and policies such as the Federal Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act.

Those required to take the training are the applicable skilled trades people, the weld monitoring organization, the production superintendents and supervisors, and the maintenance superintendents and supervisors.

5.4 People Involvement

One production superintendent stated, “Once you get ownership and pride, you can accomplish anything.” His words emphasize the value that a company can extract by empowering employees and promoting pride in one’s work. Toyota Motor Company also embraces this principle. The TPS manual states, “Experience has proven that the more authority employees have to manage their own work, the more inclined they are to pursue improvements in that work.”[23] The Automaker has been successful at fostering employee pride and empowerment on many fronts. However, most of the decision-making and improvement implement still comes from upper-level management and engineering. Toyota’s book on TPS notices, “The biggest difference between the Toyota Production System and conventional mass-production formats is the large amount of responsibility and authority that the former assigns to employees at each worksite.”[24]

The author’s team was able to assign greater responsibility and authority to the parties engaged in the weld monitoring process. The following sections discuss how assigning ownership and accountability, and increasing communication among team members enabled greater responsibility and authority for employees.

5.4.1 Ownership and Accountability

The process control team noticed a lack of taking ownership and accountability in the weld monitoring process. The team made it a priority to make the monitoring process more traceable in terms of the paper trail and the participants who were involved with problem solving and corrective action.

The redrafted nonconformance notice discussed in Chapter 5 was instrumental in outlining the authority that each party had over the weld monitoring. Please see Appendix C to reference the NCN. The NCN consists of five steps, and defines which party is accountable for each step, the deadline for when action must be taken, and signatures upon completion of required actions.

This form was created by the process control team only after each party was assembled or consulted individually for input and buy-in. Before the document was published, the production area manager, production superintendents, maintenance superintendents, weld monitors, union committee man, plant management, and the weld coordinator provided input and agreed with the final version. This process made each person accountable regarding the effectiveness of the document, since each person had a stake in creating it.

5.4.2 Communication

Several areas for improvement in communication related to process control existed at the assembly plant. Some of these issues were able to be addressed by the process control team. The major areas are highlighted below.

Dimensional Team and Launch Team

Roles

Members of both the resident dimensional team and the dimensional launch team recognized the gap in communication between the two groups. Specifically, members were confused regarding roles. Since the launch team is sent to the plant to support the resident engineers, their role is fluid and not highly defined. Unless ongoing discussion occurs to define overall responsibilities and weekly tasks, it is possible that members of either team will become confused about what the other members are doing or what they are responsible for. Discussion and documentation of these roles would dramatically reduce confusion among team members.

One helpful genre to enable communication between the two groups would be a start of shift or prior-to-shift meeting each morning. As one dimensional engineer stated, ""“All the launches I’ve ever been on had a 6:30 am meeting.” Other plants within the Automaker have experienced tremendous success by disciplining themselves to meet every morning to discuss plans for the day and work from the previous day. These meetings should be championed by the resident dimensional manager or jointly by the dimensional manager and dimensional launch manager to ensure attendance.

Process Changes

The author’s benchmarking revealed that many plants within The Automaker used a server-based logging software which helped them document and communicate process-related issues and changes among dimensional team members. In one plant, the engineers printed the previous shift’s logs each morning and carried the log with them throughout the day. The log listed the issue encountered, the corrective action taken, key dimensions or pictures, and a contact name. Those plants that were disciplined in logging process changes reaped tremendous benefits in communication and reducing confusion. Furthermore, most logging software (even excel) allows searches to be performed on keywords. Thus, a dimensional team who has logged issues for two years is able two-year repository of information on all process and product issues.

The dimensional team did not employ such as log. The author recommended such software, and several team members indicated that the software would be investigated. As one engineer said, "No one has time to look at data all day." A logging software is one mechanism which offers easily accessible information that might have otherwise taken hours or days to discover.

Weld Monitoring Community

Roles

The process control team found that the participants of the weld monitoring process did not possess defined roles or responsibilities. For example, when a weld monitor detected a discrepancy, he would sometimes contact a production supervisor. Other times, he would contact a maintenance supervisor. In order to streamline the process and communicate clearly to all parties involved, the process control team documented the roles of each participant. This documentation allowed a thorough analysis by all parties of where each party should be involved in the weld monitoring process. The process control team consisted of the people whose roles were being defined, thus buy-in was received before documentation was produced. The NCN in Appendix C provides one example of where each step nonconformance resolution process has a clear owner.

Furthermore, the process control team produced a document which listed the responsibilities and tasks of each member of the weld monitoring and nonconformance resolution team. Figure 14 shows this document.

Figure 14. Identification of Roles Regarding Weld Monitoring Process

Personnel	Responsibility	Required Actions
Operator		

DOCUMENT CONTENT REMOVED FOR CONFIDENTIALITY

Skilled Trades Person		
Supervisor		
Superintendent		
Manufacturing Engineer		

Process Changes

Similar to the dimensional team, the weld monitoring team requires communication of process issues and changes. Balasz made a similar observation in his thesis about Raytheon, "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." Balazs concluded that "opportunities for feedback must exist beyond SPC chars."[25] The process control team attempted to provide several mechanisms for the operators (weld monitors) to be integrally involved in the evolution of the weld monitoring process. The primary avenue for the operator to be exposed to information beyond "SPC charts" is the central process control boards. However, further effort should be dedicated to obtaining weld monitor feedback.

5.5 Built-in-Quality: Just-in-Time Control

One major aspect of built-in-quality pertains to just-in-time control. Just-in-time refers to the order fulfillment and delivery policy where orders are produced when a pull or order is placed for the product. This operational strategy reduces or eliminates stock inventory as well as product inventory throughout the supply chain. The policy of just-in-time production can also be applied to process control. Specifically, just-in-time can be employed as a guiding concept for when and where to monitor welds.

The process control team discovered that the locations where weld monitors checked welds could be dramatically improved. Two primary inefficiencies existed in many of the locations where weld monitors checked welds. They are:

1. The weld checks were often performed at stations downstream from where the weld actually took place
2. The amount of finished goods already welded (with the specific weld being inspected) was often unknown due to unmarked inventory

The team realized that checking welds at the point of production was critical to eliminating waste and streamlining the weld monitoring process. For example, checking a weld twenty stations downstream from where the weld actually took place means that perhaps 100 parts lay between the weld monitor and the point where the weld is occurring. If the weld is found to be discrepant, all 100 parts must be scrapped or reworked. Furthermore, weld monitors often check welds when the parts are finished and on dunnage racks, awaiting shipment to another part of the plant. This further complicates "finding the head of the snake," that is, finding the first bad part. Small parts or subassemblies are generally not marked with identification numbers to indicate the time of production. Additionally, dunnage racks on the floor may be from the prior shift's production. Thus, if a discrepant weld is found in a dunnage rack, all dunnage racks must be inspected for discrepancies, as do all of the parts after the robot that performed the actual weld.

The process control team targeted "Just-in-time" inspection as a key area to eliminating the waste that occurred due to part inspection too far from the point of production. The team worked with the weld monitors to identify all weld checks and points along the assembly line where the weld monitors could easily access or pull of a part to inspect it. The resulting check plan specified a location for each weld check to take place nearer to the point of inspection. The new inspection plan required several inspection platforms to be built to pull large assemblies off-line. The new plan also required approximately ten heavy-duty tables with vices or fixtures so that the weld monitors could secure the parts during chisel tests. Prior to these improvements, the dunnage racks served as fixtures.

Each of these tables or platforms included a shelf for the process control books mentioned in section 5.3. Therefore, the inspection stations possessed the necessary visual aids, documentation, and work instructions that the weld monitor requires. The construction of these inspection stations supported the just-in-time monitoring strategy to reduce muda and promote a responsive weld monitoring process.

6.0 RECOMMENDATIONS

Managing a process control initiative is a challenging undertaking. Certain aspects of process control demand a paradigm shift to staff at all levels at the Automaker. However, the process control team was successful in implementing a solid weld monitoring strategy as well as improving certain aspects of the dimensional control organization. This thesis highlights those accomplishments as well as areas where further improvement can be achieved through continuous improvement efforts. The following list of recommendations provides high-level insights that the author discovered to be keys to a successful process control implementation.

1. Communication must be facilitated among team members. Specifically, communication and relationships should be strengthened between the launch and dimensional teams in order to produce a high-performing team.
    a. One method to achieve this is for higher level managers, such as the Dimensional Launch Manager or the Dimensional Manager's Director, routinely attend a meeting which is designed to integrate the two groups. The author noticed that when upper-level managers attended meetings, attendance grew and the interaction was stronger.
    b. Action item lists are critical. These action item lists should include an owner and an estimated completion data. When this simple tool was utilized, attitudes and actions improved, as did timely results.
    c. Utilize a communication logging tool for process and product changes in the dimensional organization.
    d. Discuss and document roles and responsibilities.

2. Management must teach and coach employees to act proactively. Though process controls might require a large upfront investment, management must emphasize the time and efficiency savings that will be gained.

3. Management must drive the decision power to the lowest possible level on the plant floor. Employees must be empowered to apply rigorous process control continuously.

4. Worker involvement is critical in leading change initiatives. Though some improvement may be realized when process changes are forced, success will be limited. Involvement at plant-floor level is key, as this expertise is invaluable and when tapped, will lead to solid product and process improvements.

5. Align incentives to produce the desired behavior.
    a. Make quality and process controls part of performance reviews for the production and maintenance organizations. Since Maintenance and Production run the body shop, it is critical that their incentives be aligned in order to work as a partnership. Clearly, these incentives based on throughput must not overshadow a focus on quality.
    b. Upper management must emphasize and analyze the communication and cooperation between the resident dimensional team and the dimensional launch team.
6. The shop floor must perceive a pull for process controls is successful implementation is to be achieved. Generally, this pull is most effective if coming from top management. However, the initiative must be embraced by several key stakeholders, rather than by just one champion, otherwise the initiative may lose steam.

ACRONYMS

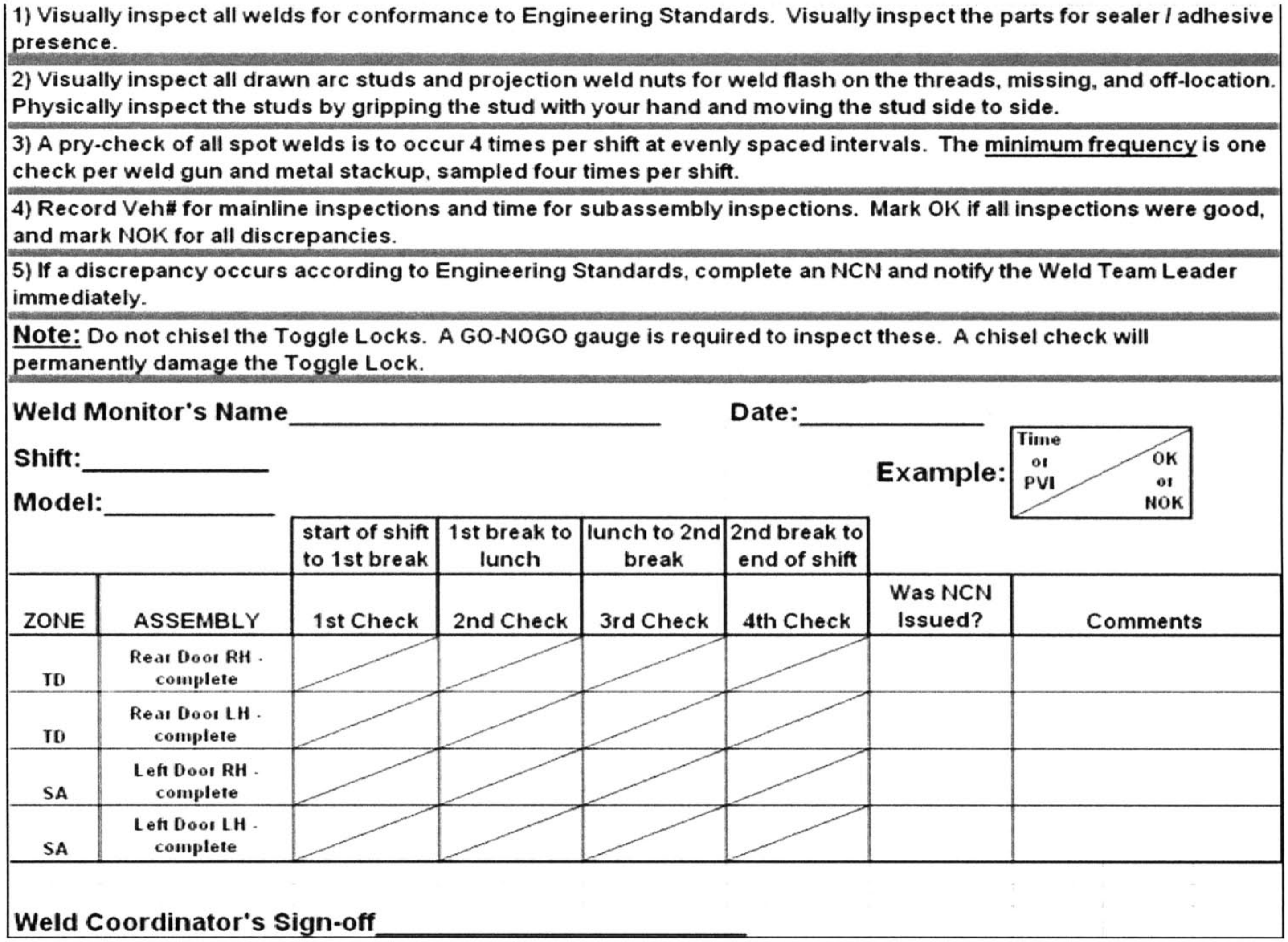
ATP	Advanced Technology Program
BIW	Body in White
CMM	Coordinate Measurement Machine
JIT	Just in Time
ME	Manufacturing Engineer
NCN	Nonconformance Notice
NIST	National Institute of Science and Technology
SPC	Statistical Process Control
TPS	Toyota Production System

APPENDIX A: 2mm Program Goals and Results Summary[26]

Goal	Result	Notes/observations
Short-run production cost impacts		
Reduce line downtime (increase capacity utilization and throughput).	Partially achieved.	• Faster problem troubleshooting, correction, and verification. • Higher sustainable line speeds, partially 2mm, partially improved tooling.
Reduce scrap/repair costs from: • Real-time quality feedback • Immediate BIW defect detection, removal, and/or repair • Rapid tool/equipment failure-identification, repair, or adjustment.	Achieved.	Estimated to be in the range of \$1-3 per vehicle. (Eastern Michigan University (EMU) 1993 and plant interviews).
Reduce BIW rework/repair costs.	Achieved.	Estimated to be approximately \$3.40 per vehicle (EMU, 1993).
Reduce body-shop labor inputs due to more efficient assembly-line maintenance and repair.	No observable change.	OCMM (Optical Coordinate Measurement Machine) use identified need to increase scope of maintenance activities. New labor inputs (e.g., dimensional engineers) now needed.
Reduce Substitute Metrology Costs: 1. Reduce CMM costs 2. Eliminate checking fixture costs.	Partially achieved. Achieved.	1. CMM still needed for other process control activities/research. 2. Elimination of checking fixtures estimated to be \$2 million in one GM plant.
Reduce Launch Costs/Time.	Partially achieved.	OEMs have reduced launch time and costs, but line integrators note that time and costs have been shifted to their sites and not a product of 2mm. Reduction of approximately \$2.50 per vehicle due to shorter launch.

Goal	Result	Notes/observations
LONG-RUN PRODUCTION COST IMPACTS		
Reduce dimensional variation through body design and construction changes.	Partially achieved.	OEMs demonstrated slip-plane panel joinery reduces dimensional variation, but little exploitation of body-shop experience in design activities.
Improve understanding of dimensional variation and its causes.	Achieved by University of Michigan.	Publicized findings in academic journals linked to 2mm activities.
Develop and test new procedures for mastering OCMMs (reducing launch times and costs),	No observable impact .	"Mastering" the OCMM cameras remains a problem. Nominal body dimensions still measured with CMM.
INDIRECT PRODUCTION COST IMPACTS		
Reduce warranty costs due to BIW quality defects.	Uncertain (some reductions likely.)	No OEM data available for estimating impacts.
Develop and establish market for analytic software for OCMM database analysis.	Developed for in-house use at GM. No commercial success for other efforts.	
MARKET IMPACTS		
Achieve 2mm (6σ) variation ("world-class" levels).	Achieved 2.5-3mm during program.	World-class standard continues to improve below 2mm.
Increase domestic-vehicle manufacturers' market share.	Achieved (see Chapter 3).	
Improve owner evaluations of vehicle quality (J.D. Powers data.)	Uncertain.	Some plants report improvements that they attribute to 2mm; other see no change or are unwilling to attribute to 2mm.
Develop market and encourage use of OCMMs in automobile plants.	Achieved.	They are standard equipment in most US auto plants.

APPENDIX B: Weld Monitor Common Inspection Sheet



1) Visually inspect all welds for conformance to Engineering Standards. Visually inspect the parts for sealer / adhesive presence.

2) Visually inspect all drawn arc studs and projection weld nuts for weld flash on the threads, missing, and off-location. Physically inspect the studs by gripping the stud with your hand and moving the stud side to side.

3) A pry-check of all spot welds is to occur 4 times per shift at evenly spaced intervals. The <u>minimum frequency</u> is one check per weld gun and metal stackup, sampled four times per shift.

4) Record Veh# for mainline inspections and time for subassembly inspections. Mark OK if all inspections were good, and mark NOK for all discrepancies.

5) If a discrepancy occurs according to Engineering Standards, complete an NCN and notify the Weld Team Leader immediately.

<u>Note:</u> Do not chisel the Toggle Locks. A GO-NOGO gauge is required to inspect these. A chisel check will permanently damage the Toggle Lock.

Weld Monitor's Name_________________________ **Date:**____________

Shift:____________

Model:____________

Example: Time or PVI / OK or NOK

		start of shift to 1st break	1st break to lunch	lunch to 2nd break	2nd break to end of shift		
ZONE	ASSEMBLY	1st Check	2nd Check	3rd Check	4th Check	Was NCN Issued?	Comments
TD	Rear Door RH - complete						
TD	Rear Door LH - complete						
SA	Left Door RH - complete						
SA	Left Door LH - complete						

Weld Coordinator's Sign-off_________________________

APPENDIX C: Nonconformance Notice (NCN)

STEP 1: DISCREPANCY DEFINITION **Weld Monitor Signature:** ____________

A) **DATE:** ____________________ **STATION / ROBOT:** ____________

eh No. / TIME DISCREPANCY DETECTED: **MODEL:** ____________

B) Weld Numbers found to be discrepant:

Describe the problem:

C) Veh. No. or Time of **last good weld inspection:**________________________ (for containment purposes)

D) Does a nonconforming weld pattern exist? YES________ NO__________

Issue the NCN to the Weld Team Leader for completion of Steps E and F.

(If Weld Team Leader is unavailable, contact Weld Coordinator for completion of Steps E and F.)

E) Weld Team Leader must immediately contact the Production Supervisor and explain the discrepancy.
F) Weld Team Leader must document Veh No. and/or location of **first bad part**

Veh #:___________________Location:_______________________

Upon request Weld Team Leader will provide a copy of the weld process data sheet showing the discrepant welds.

After completing STEP 1, forward NCN immediately to Production Supervisor and explain the discrepancy.

Weld Team Leader must record the NCN on the NCN Master Log at DD29.

STEP 2: PRODUCT CONTAINMENT (To be completed by Production Supervisor)

Describe action taken to repair discrepant welds:

FIRST REPAIR: ______________________ (Veh # OR DATE &TIME OF FIRST REPAIRED JOB)

Signature of Production Supervisor: ______________________

After completing STEP 2, forward NCN to Maintenance Supervisor.

STEP 3: EQUIPMENT REPAIR (To be completed by Maintenance Supervisor)

Maintenance Supervisor must assign root cause & corrective action to area skilled tradesman.

STEP 4: ROOT CAUSE (To be completed by area skilled tradesman assigned)

Trouble Shooting Guide. (Use to determine the Root Cause)	**YES**	**NO**	**N/A**
1) Do weld schedules in controller match spec?			
2) Is robot/PLC calling correct weld schedule?			
3) Are the correct weld caps installed?			
4) Is the cap alignment ok?			
5) Do weld caps show signs of excessive wear due to sealer contamination or insufficient water cooling?			
6) Is the tipdresser functioning properly?			
7) Is the gun welding at the correct weld force?			
8) Is the weld gun equalizing?			
9) Is weld gun programmed square to the metal?			

Describe the Root Cause:

If the Root Cause can not be determined, contact the Weld Coordinator for further investigation.

Describe corrective action taken:

Verify that root-cause and corrective actions are complete:

REPAIR BREAKPOINT: ______________________ (Veh # OR DATE & TIME OF FIRST GOOD JOB)

Skilled Tradesman Signature: ______________________

Maintenance Supervisor Signature: ______________________

After corrective action has been performed, notify Production Supervisor with the break point.
Drop off completed form in weld coordinator's mailbox at production office.

STEP 5: PROCESS VALIDATION (To be completed by Weld Coordinator)

__________ Validation Completed
__________ Schedule Certified
__________ Weld Information Database Updated

__________ Weld Tool Information Updated and Posted
__________ NCN Closed on NCN log

Weld Coordinator Signature: ______________________

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