

Improving the Acquisition and Implementation of In-line Factory Measurement Systems

by

Michael P. Rutz

B.S. in Mechanical Engineering
University of Michigan (1993)

Submitted to the Departments of Mechanical Engineering and Management in Partial Fulfillment of the Requirements for the Degrees of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING
and
MASTER OF SCIENCE IN MANAGEMENT

at the
Massachusetts Institute of Technology
May 12, 1995

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Abstract

Optical coordinate measurement machines (OCMMs) have proven to be an effective tool for reducing product launch times, increasing customer satisfaction, and reducing overall manufacturing costs in the automotive industry. With the ability to measure 100% of body-in-white assemblies and stamped parts, OCMMs can provide detailed tracking of process trends, real time data analysis, and measurement of process variation. OCMMs are not a silver bullet for the current cost and quality problems facing U.S. automotive companies. However, manufacturers who can effectively use OCMM technology to improve vehicle quality and manufacturing costs will gain a significant competitive advantage and be able to better utilize new and more capable process measurement technologies.

Despite the many advantages of OCMM use, however, many installations have been ineffective in their acquisition, implementation, and utilization of OCMM systems. This research investigates and seeks to improve OCMM use at Chrysler Corporation's Warren Truck Assembly Plant (WTAP), a plant that has struggled with the implementation of these systems for over five years. Specifically, this research investigates three areas that are critical to the successful acquisition and implementation of OCMM equipment and similar process measurement technologies- technical design and system competence, equipment supplier relations, and management practices. Together, these topics provide insight into the things gone wrong at WTAP and provide the basis for a recommendation of best practices for OCMM implementation.

From this research I draw several conclusions. First, automotive manufacturers that can effectively use OCMM and OCMM-based technology within the confines of a larger dimensional control strategy are in position to gain competitive advantage. As advances in OCMM technology continue to increase, those manufactures that can effectively integrate OCMM use within a top-down dimensional control strategy will be better able to capitalize on these advancements in order to improve vehicle cost and quality. Second, effective technology acquisition (for OCMMs and other technologies) requires that

processes be designed and implemented with a focus on system metrics and tolerance chains. During design and acquisition, systems and sub-systems must be acquired with minimal decomposition of tolerance chains and specified with emphasis on meeting system-level specifications. During implementation and operation, work and accountability must be effectively organized around system tolerance chains in order to facilitate communication and insure proper system functioning. Third, successful implementation of new technology requires that organizations be flexible and able to learn. This implies that organizations who focus on skill development and foster an environment in which learning and improvement can take place will remain competitive in the long-term.

Thesis Advisors:

Charles Fine, Associate Professor of Management Science

Daniel Whitney, Senior Research Scientist and Lecturer in Mechanical Engineering

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Ch. 1 Introduction to Thesis

For the past decade, the U.S. automotive industry has been chasing worldwide automotive producers to regain a competitive advantage in cost and quality. As a result, significant improvements have been made in vehicle costs, design, and lead times. However, as the 1994 J.D. Powers Initial Quality Survey reports, U.S. producers still trail best in class quality in nearly every major quality area.

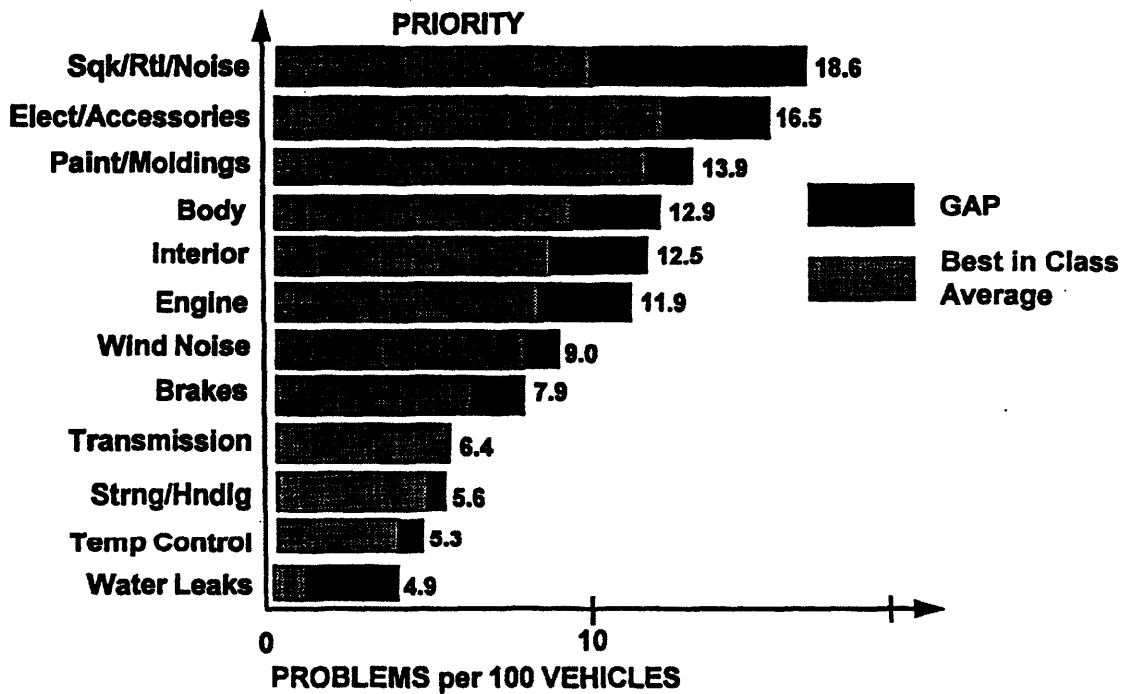


Figure 1. 1994 J.D. Powers Initial Quality Survey (U.S. vs. Best in Class)¹

No where is the gap between the U.S. and best-in-class more pronounced than in the areas related to stamping and body-in-white (BIW) assembly. Squeaks/rattles/noise, body, wind noise, steering/handling, and water leaks are all areas that are highly valued by customers, current sources of competitive disadvantage, and affected by the quality of the BIW assembly. Therefore, to improve in these areas, significant effort has recently been put forth by the U.S. government and the major U.S. automotive companies to reduce body-in-white variation.

¹ Presented at "2mm Program" Workshop, Auburn Hills, MI, Nov. 2, 1994.

In 1992, a major initiative of this effort was begun with the establishment of the "2mm Program". The "2mm Program" was created through the Auto Body Consortium (ABC)² with sponsorship from the University of Michigan, General Motors Corporation, Chrysler Corporation, Perceptron, Inc., and several other small tooling companies in order to reduce body-in-white variation and improve overall customer satisfaction within the U.S. automotive industry. To accomplish this, the program has heavily researched BIW variation by working directly with the automotive companies and by relying heavily on optical coordinate measuring machine (OCMM) data. OCMMs are ideally suited to assist this research because of their unique ability to track process trends and changes by measuring 100% of production.

As a result of this research effort and the perceived value of variation reduction, OCMM use has expanded rapidly in the U.S. automotive industry. With the assistance of the "2mm Program", OCMMs have not only assisted in the detection and reduction of body-in-white variation, but they have also proven to be an effective tool for improving product launch times and reducing overall manufacturing costs.

In addition, the continued use of OCMMs within the automotive industry is only expected to expand in the coming years. U.S. automotive companies have already made large investments in OCMM equipment and are continuing to invest in new applications. To date, nearly every U.S. owned plant currently has OCMMs and use in Europe is also widespread. Furthermore, additional equipment based on OCMM technology continues to be developed and will provide even faster more efficient methods for measuring process trends and build quality in order to assist in the reduction of build variation.

OCMMs are not a silver bullet for the current problems facing U.S. automotive companies. However, effective OCMM use and organizational commitment to variation reduction can be a source of competitive advantage for manufacturers dedicated to improving quality. Manufacturers who can effectively use OCMMs and OCMM-based technology to improve vehicle quality are better able to satisfy customers and will be better able to utilize new and more capable technologies. Therefore, manufacturers committed to improving quality, launch times, and manufacturing costs must learn how to effectively use these systems and they must do so quickly as competitive requirements increase.

² A consortium of U.S. automotive manufacturers created in part to assist in government funded research.

Despite the tremendous benefits and potential of these systems, however, many companies have been unsuccessful in their attempt to implement these measurement systems. Even from plant to plant within the same company, these systems have had varying success. And although significant resources have been spent to improve OCMM use, problems continue to exist in the acquisition and implementation of these systems.

1.1 Research Focus and Objectives

I have been working at Chrysler Corporation's Warren Truck Assembly Plant (WTAP) in order to learn about these systems and to improve WTAP's use of these systems. WTAP is a plant that has struggled with the implementation of these systems for several years. I have seen the results of these frustrations and have met my own frustrations in my attempts to improve these systems.

Specifically, this research focuses on the three major topics that are critical to the successful implementation of these systems. First, the technical competence of the systems at WTAP will be discussed to provide a foundation and understanding of the current technical problems with the existing systems at WTAP. Second, supplier relations will be explored in order to understand why the OCMM equipment at WTAP was ineffective from the start. And finally, management practices will be explored to determine what went wrong and what needs to be done to improve WTAP's OCMM systems.

In addition to analyzing WTAP's OCMM systems, this thesis will also detail the use of OCMM's at Chrysler's Jefferson North Assembly Plant (JNAP). JNAP has been the most successful OCMM installation at Chrysler and provides a very useful comparison to WTAP. Also, because JNAP has made significant advances in their use of OCMMs, JNAP can serve as a blueprint for the improvement of OCMM use at WTAP. Therefore, in addition to providing data for a set of best practices, analysis of JNAP will also help to illustrate where and how WTAP must improve.

The objectives of this research are twofold. First, by developing a common understanding of the things gone wrong at WTAP, this research will provide a learning opportunity for those at WTAP and at Chrysler. The problems plaguing OCMM implementation at WTAP are in no way representative of the current state of manufacturing Chrysler or WTAP. However, these problems do serve as a reminder of

what can happen when equipment acquisition and implementation is ineffective. Second, this research will provide recommendations to assist the men and women of WTAP in the effort to improve their use of these systems. As I conclude my involvement with this project, plans are being made for the mechanical improvement of these stations based on the mechanical problems detailed in this thesis. These plans, if implemented, should help to eliminate many of the current technical problems that have prevented the systems at WTAP from functioning properly. However, these mechanical enhancements are only a small part of the commitment and change that will be necessary to fully utilize these systems.

1.2 Motivation for This Research

The primary motivation for this project is the need to maintain quality and productivity improvements at WTAP. Therefore, this project is an attempt to provide continuous quality improvements to WTAP through the improved utilization of WTAP's OCMM systems. WTAP has made a significant financial investment in these systems (several millions dollars in manpower and equipment) and is currently not leveraging the large opportunity for quality improvement that these systems provide. Better OCMM use at WTAP will assist in the reduction of BIW variation, early detection of BIW scrap, and improvement of process up-time. Together, these benefits will result in increased customer satisfaction and reduced manufacturing cost. Better OCMM use will also provide better utilization of the "2mm Program" team at WTAP whose primary function is to use OCMM data in order to reduce variation. This project, which focuses on the improvement of OCMM use, is therefore necessary and appropriate in order to improve productivity and quality at WTAP.

The problems associated with these systems are also important because the impact of the successful use of these systems expands far beyond the data that can be retrieved from the stations. The analysis of the problems with OCMMs at WTAP uncovers larger cultural and organizational barriers that have a dramatic effect on the overall performance of WTAP. In learning to use these systems, many of these barriers will simultaneously be eliminated. Ultimately, one of the most powerful competitive advantages an organization can have is a quality focused and participative workforce. Therefore, one of the greatest benefits of this technology could come from using it as an impetus for cultural change in the body shop.

Finally, lessons learned and the recommendations resulting from this research can be applied to most other technology purchases. Although the technology may differ, the management of suppliers, coordination of users, and need for organizational change are often the same. This paper will offer in-depth analysis of optical gauging equipment. But the problems and issues that will be surfaced are in many cases just symptoms of the deeper problems that afflict many manufacturing companies in the U.S. Technology similar to OCMMs will continue to be developed and those manufacturers who can quickly implement this technology will have a significant competitive advantage.

1.3 Intended Audience

There are several intended audiences for this thesis. First and foremost are the men and women of WTAP who have struggled in their attempt to use these systems. The analysis and recommendations contained in this thesis are directed primarily toward WTAP and should assist WTAP in the improvement of their OCMM use.

Second is the broader Chrysler audience including other plants and engineering staffs that must use or acquire this equipment. The lessons that can be learned from this example can also be applied to many other plants within Chrysler that are facing similar problems.

And finally, students and academics studying equipment acquisition or cultural change in manufacturing environments are the third audience. The problems that this thesis addresses are in many ways symptomatic of the deeper issues confronting American manufacturing and should help to deepen the readers' understanding of manufacturing and manufacturing related issues.

1.4 Thesis Overview

This thesis is written to provide both the necessary background for readers not familiar with optical gauging or Chrysler Corporation and the necessary details for those individuals at Chrysler who will attempt to implement or use the information contained in this thesis. Following is a chapter by chapter overview of the remainder of this thesis.

Chapter 2 serves as an overview chapter in order to introduce the reader to dimensional control and optical gauging. This chapter will provide the background information necessary to understand optical gauging's position within the broader dimensional control

strategies of automotive companies. In addition, the chapter will explore the technical foundations for OCMM accuracy and data use.

Chapter 3 discusses the specific OCMM systems and operating environments present at Chrysler's Warren Truck Assembly Plant (WTAP) and Jefferson North Assembly Plant (JNAP). In addition, a short benchmarking section will detail OCMM use at other automotive companies.

Chapter 4 focuses on the implementation of OCMMs and provides an analysis of things gone wrong at WTAP. Two areas, technical competency of OCMM systems and equipment supplier relations, will be discussed in order to detail the existing problems with OCMM use at WTAP and explain in part how these problems came to be.

Chapter 5 will examine how WTAP must learn and change in order to begin to successfully use OCMMs. Specifically, this section will explore a concept called double-loop learning and will attempt to provide WTAP with a path toward improvement.

Chapter 6 will present specific recommendations for improving OCMM use at WTAP and equipment acquisition at Chrysler. This "plan" summarizes the analysis and learnings contained in the body of this thesis.

A few final notes before you begin. In many cases, I have attempted to emphasize both the weaknesses and strengths of WTAP in order to elicit a set of best practices. Because these stations have not been used successfully for several years, however, many sections in this paper emphasize weaknesses rather than strengths in order to best communicate potential areas for improvement. This approach, however, should not mislead readers into believing that WTAP is a troubled facility. To the contrary, WTAP is an excellent manufacturing facility in many respects and their willingness to address these problems is evidence of their desire to improve.

In addition, because this paper represents only a snapshot in time, it cannot effectively detail the dynamic nature of improvement at Chrysler. As a result, it is important to realize that at the time of publishing many of the problems raised in this paper have been or are being addressed by WTAP and Chrysler.

Ch. 2. Optical Gauging- A Generic Overview

In order to understand the complexities and potential problems with OCMM use, it is first necessary to understand why OCMMs are needed and how OCMMs actually operate. Therefore, this chapter will present necessary background information about OCMM equipment in order to provide context for recommendations and issues in subsequent chapters.

Beginning with an overview of dimensional control strategy and OCMM equipment, this chapter will provide insight into the strategic level need for OCMMs and the technical foundation of OCMM use. The themes initiated in this chapter will recur throughout this paper and will help to provide both basis for the strong support of this equipment throughout the U.S. automotive industry and an understanding of current implementation problems with OCMMs.

2.1 Dimensional Control Strategy for Body-in-White Production

Because body-in-white (BIW) assemblies constitute the central vehicle base to which all other vehicle components are attached, special attention must be paid to insuring BIW dimensional accuracy. Variation created in the BIW assembly is often magnified throughout the assembly process resulting in difficult down stream assembly and possible problems with front-end alignment, engine installation, instrument panel fit, interior trim fit, etc. Therefore, the central goal of most dimensional control strategies in automotive assembly plants is to build high quality BIW assemblies.

In order to build a high quality BIW assembly, automobile manufacturers must focus on one thing: building the BIW assembly to given design tolerances consistently. To accomplish this, vehicle manufacturers must first design a manufacturing process that can successfully assemble a vehicle to given design specifications and then insure that the process can build the BIW assembly to tolerance consistently. This necessitates strong coordination between product and process designers and an effective coordinate measurement system in order to verify production quality. The remainder of this section will focus on how product and process design must coordinate in order to successfully establish an effective coordinate measurement system capable of providing useful dimensional information. OCMMs, the focus of this paper, are one element of this coordinate measurement system.

2.1.1 Effective Product and Process Design

The design phase is most critical in determining dimensional accuracy and process capability. Therefore, it goes without saying that significant time must be spent up front to design products and processes that allow for the effective manufacture of vehicles. However, time can be greatly reduced if product and process designers coordinate and have in place effective requirements to insure a smooth transfer between product and process design. In addition, these requirements must allow and facilitate the correction of process and product designs based on actual production measurements. To accomplish this there are several methods that can and should be used to insure that products and processes are designed with the necessary flexibility to insure effective assembly.

One requirement that can significantly reduce the coordination time between product and processes designers and speed the feedback of product or process design problems is the use of well-defined critical interface points (CIPs). In many automotive companies, CIPs are defined for each part or sub-assembly and serve as the critical dimensions that must be held to the tightest tolerances in order to insure that all parts mate properly. If a process can successfully manufacture these points to tight tolerances, the resulting assemblies and products will be of high quality. Therefore, it is important that these critical interface points be well-defined and that tooling and processes be designed so that these points can be built to specification.

The accuracy of these CIPs also serves as an effective metric on the shop floor in order to gauge process performance. With a measurement system in place, CIPs can be monitored and product quality can be maintained and improved. In order to facilitate this step, however, knowledge of process design must also be included in the analysis of CIP accuracy. Therefore, another critical component of a dimensional control plan is the inclusion of tooling locations and rest points that are used to locate CIPs during assembly. Because tooling locations often have the largest impact on CIP accuracy, their inclusion into a dimensional control plan is necessary in order to allow for the interpretation and use of dimensional data.

For instance, if data indicates that a CIP is drifting on a door assembly, someone must interpret the data and determine why the door is being assembled out of specification. To do this, it is very helpful to have a map back to the process so that critical process steps

can be investigated. In addition, it is helpful to understand how product and process design can impact the quality of the part. In the end the cause may be bad incoming parts, poor part design, poor process design, or a process breakdown. However, the ability to quickly investigate possible causes greatly simplifies root cause analysis and enables quicker, more effective solutions.

Thus, the definition of CIPs combined with a clear understanding of the process design is critical in order to provide a feedback map when actual CIPs are drifting. Together, these two elements can provide a clearly defined path back to either the process or product design so that improvements can be made. The next section discusses the development of an effective measurement system within a plant that can help to monitor CIP quality, detect possible CIP problems, and provide insight into why problems have occurred.

2.1.2 Development of an Effective Measurement System

Given a set of clearly defined measurement points (CIPs) for final assemblies and each critical sub-assembly, an effective measurement process must then be established in order to measure actual process output in order to verify and improve dimensional accuracy of parts and sub-assemblies. To accomplish this a variety of equipment is available.

The three most common measurement devices are mechanical coordinate measurement machines (CMMs), optical coordinate measurement machines (OCMMs), and check fixtures. Because check fixtures are rapidly being replaced by CMMs and OCMMs, this paper will not go into further detail about them. Thus, we are left with two primary measurement devices, CMMs and OCMMs. In most cases, both are required due to the dual desire of a plant to 1) measure process trends (i.e. be a process monitor) and 2) measure detailed part geometries (i.e. be a product monitor).

OCMMs are used primarily for measuring trends in vehicle coordinates. Therefore, OCMMs are considered to be a process monitor because these trends provide more information about the process than they do about an individual part. OCMMs are ideally suited for this job because they are located in-line (i.e. they are part of the process) and they measure every vehicle on the line. This in-line capability is permissible due to the fast OCMM cycle times (often less than 30 seconds) enabled by optical measurement.

Mechanical CMMs are used primarily for measuring detailed part geometries. Therefore, CMMs are considered to be product monitors because they accurately measure individual part geometries. CMMs are ideally suited for this job because they have the accuracy and the flexibility to measure a multitude of different points on different parts with only simple program modifications. This is a great advantage when more detailed information must be gathered about a specific part feature. In order to change a measurement point on an OCMM, cameras must be re-aligned, coordinates must be recalculated, and all of this must be done when the assembly line is stopped.

Recently, high speed mechanical CMMs (HSCMMs) have been placed in-line to combine the benefits of OCMMs and tradition mechanical CMMs. Unless multiple HSCMMs are located in parallel (which is a very expensive alternative), however, cycle times prevent these systems from measuring 100% of production. Other new machines that combine OCMM and mechanical CMM technology are also currently being developed and may soon be a realistic alternative to OCMM and mechanical CMM systems.

Together, this equipment, providing the capability to measure both product and process quality, comprises the essential ingredients of a measurement system for automotive dimensional control. Currently, there is debate about the ideal combination of this equipment for a given plant. At Chrysler, many plants have chosen to use OCMMs for in-line inspection and CMMs for off-line inspection. However, other plants have decided against OCMMs and have gone with all HSCMMs. Thus, there appears to be no uniform strategy on the best mix of dimensional control equipment. However, some combination of mechanical CMMs and OCMMs is probably ideal depending on the product mix at the plant. Analysis of WTAP and JNAP will offer additional insight into this issue.

2.2 Optical Gauging Using OCMM Systems

First used in the 1960's, vision technology has expanded in the past several years into a multi-billion dollar industry. Optical gauging, only a small segment of this industry, has only recently seen wide scale use due to advances in processing speed and optics technology. As applications and capabilities continue to increase, however, it appears that optical gauging and OCMM use will continue to grow in the coming years.

Currently, Perceptron, Inc., founded in 1981, is the sole worldwide supplier of OCMM systems to the automotive industry. Diffracto, Ltd. had been one of the early competitors

in the OCMM business. However, in 1990, Perceptron became the sole supplier when it purchased the portion of Diffracto's OCMM business specializing in the measurement of BIW assemblies and stampings. Today, although there are some Diffracto systems still in use, the majority of installations are Perceptron.

2.2.1 System Overview

An OCMM is essentially an assembly line station used to measure a set of specific points (holes, edge points, or any corner points) on a stamped part or a BIW assembly (both referred to as parts). The primary components of an OCMM system are the cameras (used to measure the part), the camera support structure (used to position the cameras), the system controller (used to calculate and display data), a conveyor system (used to move the part in the station), and a lifter or other locating device (used to accurately position the part in the station). Together, these components allow for the automated, in-line measurement of stamped parts and BIW assemblies.

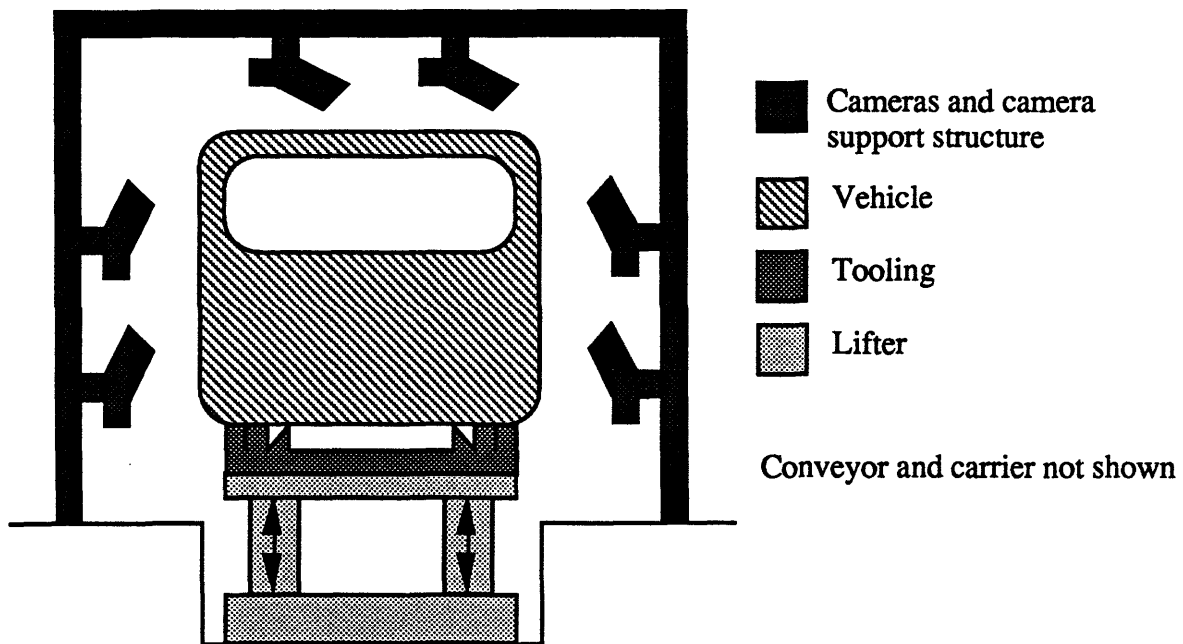


Figure 2. Cross-section of Typical OCMM Station with Mechanical Fixturing

The measurement process itself is fully automated and completed in less than 30 seconds. Parts are typically moved into the OCMM station (by carrier or conveyor), located in the station (by camera or lifters), measured by the OCMM, and released from the station. In

the mechanical fixturing system shown in Figure 2., a carrier would bring the vehicle into the station, a hydraulic lifter would lift the body off the carrier in order to locate the body on the lifter tooling, then the OCMM cameras would measure the vehicle, and finally the lifter would lower and the carrier would move the vehicle from the station.

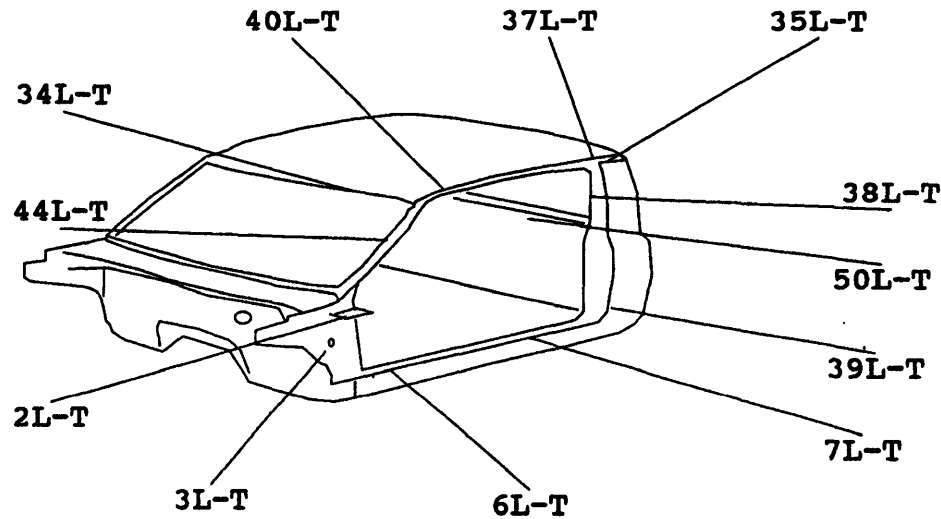


Figure 3. Measurement Points for Cab Sub-assembly

2.2.2 Relative Coordinate Frames and Tolerance Chains

As with all coordinate measurement devices, total system accuracy for OCMMs is dependent on the accurate translation of the relative coordinate frames located in the measurement system. Therefore, this section will go into some detail about the coordinate reference frames and associated tolerance chains within a typical OCMM station in order to describe the key interfaces that must be maintained in an accurate system. These concepts will provide a basis for the discussion of test results and analysis of supplier and organizational responsibilities for these systems discussed later in this paper.

As an example of how coordinate reference frames affect the overall system accuracy of OCMMs consider the measurement of a particular point on a vehicle body. In order to relate that point to other points on the vehicle the measured point must be located relative to the coordinate frame of the vehicle which is defined during vehicle design. Therefore, the coordinates of each measurement point must be translated through all of the relative frames in the coordinate measurement system until a mathematical relationship is

established between the measured point and the base vehicle frame. Any errors that are introduced into this mathematical relationship will result in inaccuracies in the measurement system. To understand how and where inaccuracies can occur we must look more closely at the relative coordinate frames within a OCMM system.

Figure 4. shows the location of the relative coordinate frames for an OCMM system. Again suppose a particular point on the vehicle needs to be measured (Point A). In this case we would want to determine the translation between Point A and the base vehicle frame, B. This translation is defined as $T(A,B)$. To determine $T(A,B)$, each relative frame (from A to I) must be translated.

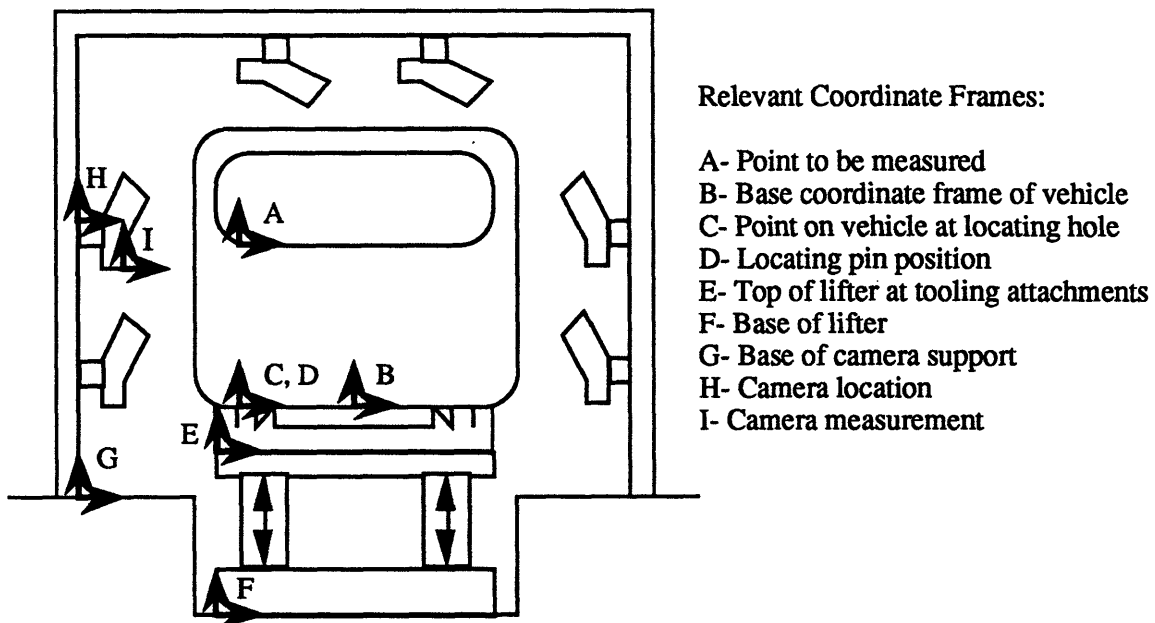


Figure 4. Relevant Coordinate Frames for OCMM Measurement

Thus the formulation would be:

$$T(A,B) = T(B,C) T(C,D) T(D,E) T(E,F) T(F,G) T(G,H) T(H,I) T(I,A)$$

This formulation says is that in order to determine the location of a point on the vehicle using an OCMM camera, you must know:

the location of Point A relative to the camera view, $T(I,A)$

the location of the camera view relative to the camera, $T(H,I)$

- the location of the camera relative to the base of the camera support, $T(G,H)$
- the location of the camera base relative to the lifter base, $T(F, G)$
- the location of the upper lifter relative to the lifter base, $T(E,F)$
- the location of the upper lifter relative to the tooling, $T(D,E)$
- the location of the tooling relative to the vehicle Primary Location Points (PLPs), $T(C,D)$
- the location of vehicle Primary Location Points (PLPs) to the base vehicle frame, $T(B,C)$

The difficulty of achieving this translation accurately can be investigated by analyzing the tolerance chains that tie these reference frames together. Figure 5. is a simplified drawing of the relative reference frames in an OCMM station and clearly shows the tolerance chains between each reference point. The camera system and fixturing system links are shaded to indicate their criticality to the overall tolerance chain.

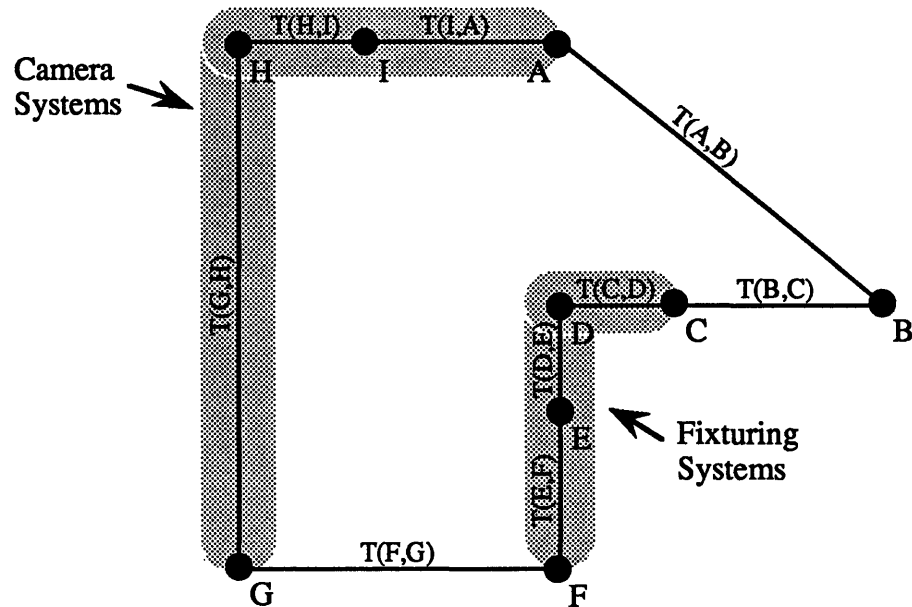


Figure 5. Tolerance Chain for OCMM Reference Frames

By investigating these tolerance chains, possible sources of error can be isolated and investigated. For instance, errors due to the camera systems or fixturing systems (shaded in picture) can be decomposed into their sub-components and root causes can be quickly determined.

These links can also provide insight into the complexity of acquiring and operating these systems successfully. In general, the more organizations that have responsibility for part

of this chain, the more difficult it is to achieve system accuracy. Thus, the number of organizations with responsibility for part of this chain becomes a useful metric to evaluate the complexity of system acquisition or operation. During operations, this would imply that having one group responsible for all chains would simplify operations by reducing necessary communication and coordination. During equipment design and acquisition, this would imply that having fewer suppliers or functional areas involved in acquiring the system would improve the chances for a successful system.

Because the translation of these relative reference frames is critical to the total system accuracy of an OCMM, OCMM manufacturers have developed effective ways to determine translations. Perceptron, Inc. has developed a method called VeriStar™ in which the translation between a point in space and the base coordinate frame of the vehicle is calculated by computer. In this process, theodolites are used to calibrate the OCMM cameras and locate them in reference to the coordinate frame of the vehicle. This process attempts to resolve all of the relative reference frames by providing an absolute reference path between the camera point and the vehicle body. This translation is then used by the OCMM controller to automatically translate each measurement into the base coordinate frame of the vehicle during regular use of the system.

These translations can breakdown however in a dynamic measurement system when relative reference frames shift during use of the system. For example, if tooling moves or becomes loose, the estimation of $T(D,E)$ used by the OCMM controller is no longer accurate and the overall system accuracy is reduced. The next two sections will focus on the areas that are critical during dynamic measurement conditions, the camera and fixturing systems.

2.2.3 Camera Systems

The camera systems comprise the tolerance links from frame G to frame A ($T(G,H)T(H,I)T(I,A)$). Actual measurement takes place by a method called laser triangulation in which a laser line is projected onto the surface to be measured and that image is recorded by a light sensor attached to laser (see Figure 6.). Based on the dimensions of the laser line, the location of the point with respect to the camera can be determined, $T(I,A)$. Then based on the translation equations, the point can be translated into the base coordinate frame, $T(A,B)$. The position and aim of the camera, $T(G,H)T(H,I)$, is adjusted by physically changing the position of the camera. Cameras

are typically located between 200 millimeters and 800 millimeters from the measurement surface (newer technology continues to increase this distance) and are affixed to the rigid housing that encloses the OCMM station.

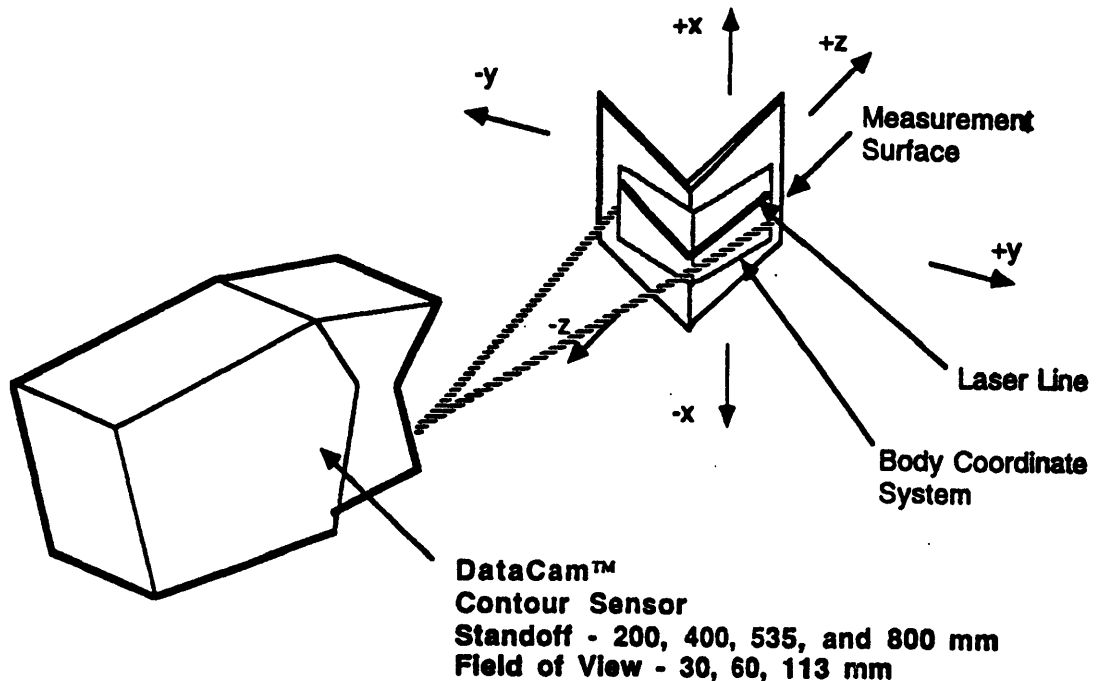


Figure 6. Optical Measurement of a Corner Point³

Error in the camera systems can be introduced by a variety of causes that include bad lighting, surface contaminants on the vehicle, lens contaminants, gross vehicle misposition, misalignment of the camera, or mathematical estimates used by the computer software. In most cases, effective routine maintenance (to include cleaning of cameras, tightening of camera fixtures, adjustment of camera exposure, etc.) and careful set-up (to include VeriStaring™, camera placement, lighting, etc.) can greatly reduce the occurrence of these errors.

2.2.4 Fixturing Systems

The fixturing system comprises the tolerance links from frame C to frame F and is typically the most critical component of the measurement process. The role of the fixturing system is to locate the part in the OCMM station so that the base coordinate frame of the vehicle, frame B, can be located relative to base of the lifter, frame F.

³ Picture copied from Perceptron sales brochure.

Fixturing is a dynamic process and can be cause for position inaccuracies that can introduce error into the reference frame calculations done during VeriStaring™.

There are two primary methods for locating the body in the OCMM station: visual fixturing and mechanical fixturing. In both of these cases the body is usually positioned using a 3-2-1 locating scheme (depending in the rigidity of the vehicle body) in which all axis of rotation and translation are restricted. Because of their relevance to WTAP's OCMM problems, I will go into these two methods in more detail.

In visual fixturing, the body is mechanically rough located in the OCMM (to within 10mm) and cameras are used to measure the PLP points on the underside of the vehicle in order to locate the base reference frame of the vehicle. In mechanical fixturing, pins and pads are used to locate the body. These pins and pads are generally located on a lifting mechanism that moves the pins into place. In some cases, the body can be also be lowered onto the tooling.

The biggest advantage of visual fixturing is that it can effectively eliminate potential downtime problems with carriers, lifters, and tooling. Because the part can be rough located, complex tooling and the need for tooling maintenance are eliminated. Thus, visual fixturing can dramatically reduce the involvement of the skilled trades in the operation of the station. This is a significant benefit in older plants, like WTAP, with traditional work rules.

Visual fixturing also has several disadvantages when compared to mechanical fixturing. First, visual fixturing does not locate the body similar to most other production stations. Typically there are few clamps or pins in visual fixturing stations and therefore it is very difficult to apply learnings about repeatability problems in the OCMM station to other processes in the body shop that use clamps and pins. Second, visual fixturing requires that cameras are fully orthogonal to measurement surface (i.e. directly below PLP holes). This often necessitates the re-design of station tooling to allow for camera placement and could be cause for contamination problems. Third, visual fixturing still requires that the body be located within a 5-10mm tolerance. If the carrier alone cannot guarantee this, a lifter or other location device would be needed.

Throughout Chrysler and General Motors, mechanical fixturing is the preferred method for locating BIW assemblies. However, Ford has recently switched to visual fixturing for

its new systems. Thus, both systems have proven effective in actual use and opinions differ as to which method is most effective. At WTAP, visual fixturing is a very viable option that could have major benefits over mechanical fixturing given the current problems WTAP is facing. These problems will be addressed later in this paper.

2.2.5 Using OCMM Data to Improve Product Cost and Quality

The real value of any measurement device is only leveraged when the data are used correctly to improve the quality and cost of the final product. Therefore, significant effort is required to use OCMM data effectively. As shown, insuring the accurate recovery of OCMM data can be complicated and difficult. However, analyzing that data and making significant improvements to the product or process is even more difficult. Therefore, it is not surprising that this is the area where most OCMM users have been most ineffective.

Today, with fast and highly sophisticated measurement devices, most plants have more data than they could possibly act on. However, without an effective method for tracking part data back to the process, much of this data is unusable. OCMM data simplifies this tracking process by detailing the dynamic nature of process changes. Therefore, to be most effective, OCMM data must be used for real-time detection of problems and for detailed analysis of process changes. This has required that new analysis methods be developed to fully utilize this capability.

Real-time use (i.e. signaling defective part by alarms)

Real time defect detection is most valuable when used as tool to inspect for defects, detect scrap, and alert operators that the system is out of control and needs attention. OCMM controllers provide the ability to define tolerance limits for all measurement points. Knowing where and how to set the critical tolerance limits of specific dimensions in order to insure that only defective assemblies are flagged is a very difficult and requires intimate vehicle knowledge. When done properly, however, points that are out of specification can be flagged and workers can be alerted to problems when they occur. Without OCMMs, problems are often not detected until the end of the body shop or in some cases until the product is completely built.

A good example of real time detection would be the measurement of windshield openings. Because proper windshield opens are not visibly detectable in the body shop, problems are often only detected during the actual installation of the windshield. This

results in high rework and scrap costs. However, by detecting and solving these problems at the OCMM station, significant time and money can be saved. Other examples of problems that could be identified early would include broken clamps, loose or broken locating pins, and bad incoming parts.

Analysis

The central goal of OCMM data analysis is variation reduction. Therefore, analysis of OCMM data is a far more complex and time consuming process than the real time use of the data. The basic approach to OCMM data analysis has been designed by the "2mm Program" based on their experience with several plants. Basically, the "2mm Program" prefers a case study approach in which detailed investigations of variation causes are detailed and solutions are documented. The general methodology for improvement of variation is shown in Figure 7.

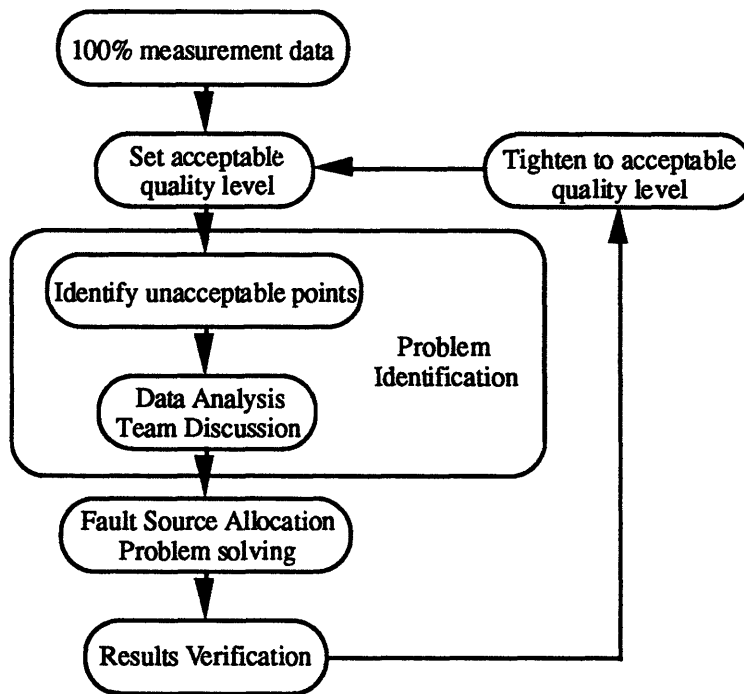


Figure 7. "2mm Program" Variation Reduction Methodology⁴

These case studies use a team-based approach to systematically determine the root causes of variation and ultimately to find solutions to those root causes. During this phase, effective product and process design is critical in reducing the difficulty of tracking and eliminating variation causes. A team-based approach is necessary because effective

⁴ Diagram created from "2mm Program" literature.

analysis requires process, product, and statistical knowledge that can seldom be found in one individual. Once several of these cases are completed, a knowledge base can be created that will greatly reduce the analysis time for many subsequent problems. The results of this type of analysis can have many broad reaching effects as detailed below.

First, assembly variation can be measured and reduced. Variation reduction, which focuses primarily on part to part variation of stampings and BIW assemblies, has always been an important goal of automotive assemblers because of its impact on quality and customer satisfaction. However, only since the invention of OCMMs have assemblers had the necessary data to effectively understand and eliminate variation. OCMMs are the ideal tool for measuring and reducing variation because of their high sample sizes and their ability to provide data about process trends and mean shifts that no other measuring equipment can provide.

To measure variation of an automobile, large sample sizes are collected and used to determine the 6-sigma variation for all critical points. For each critical point, 99.74% of the vehicles measured would fall within that 6-sigma value. Once individual point variation is determined, overall vehicle variation is calculated by rank ordering the variation of each measurement point and selecting the variation of the 95th percentile point. Typically, a total BIW variation of less than 2mm² is considered world-class.

Variation within automotive assemblies can be caused by incoming part quality, product design, process design, and maintenance of the process. This variety of sources makes the determination and elimination of variation very difficult. Typically, OCMM data is recovered at or near the end of the BIW assembly process. Thus, OCMM data can show that there is a need to reduce variation at a specific point on an assembly. However, because it cannot show where the variation is coming from, tracking and root cause analysis can be very difficult. A well-defined measurement process in which CIPs and process tooling locations are well defined can ease this process. However, ultimately effective solutions still require highly skilled people with an understanding of product, process, and statistics. Several studies are currently ongoing to improve and simplify the data utilization process (e.g. The Process Navigator⁵). At this time, however, there is no substitute for experience.

⁵ Presented at "2mm Program" Workshop, Auburn Hills, MI, Nov. 2, 1994.

OCMMs can also assist in the improvement of process up-time by enabling the detection of negative trends before catastrophic failure occurs to tooling and providing data and trending necessary for the establishment of an improved preventative maintenance (PM) program. OCMM data can be used as a predictive measure (i.e. the tooling can be replaced when the data trends indicate wear or looseness) or as a schedule for preventative maintenance (i.e. wear trends could be used to determine an effective PM schedule). Ultimately, the early detection of possible tooling failures and the implementation of an effective PM program will significantly improve process up-time which will lead to increased productivity, decreased overtime costs, and longer equipment life.

Finally, the skill development and empowerment of skilled trades workers on the floor to analyze data and make process improvements can have dramatic effects on the long-term competitiveness of the plant.

Together these capabilities make OCMMs an effective tool for reducing variation, eliminating scrap, and improving process up-time. It is important to realize, however, that because OCMMs are only an enabling technology, the quality impact of these systems is largely dependent on how the data are used. Although methods are under investigation to further automate the data utilization process, ultimately process improvements are the result of hard work by skilled individuals.

Chapter Two Conclusions

This section helps to point out three important points about OCMM technology and its use. First, effective OCMM use requires effective measurement system design and a path back to product and process design. OCMMs must be part of a larger dimensional control strategy and a path must exist between the measured data and product and process design in order to facilitate quality improvements. Second, accuracy of OCMM systems depends on the successful translation of coordinate frames within the systems. Therefore, these frames and the tolerance chains that connect them must be maintained effectively in order to insure system accuracy. Third, OCMM technology is here and can have a tremendous impact on cost and quality if used properly. Therefore, manufacturers must learn to use this technology in order to remain competitive in the future. OCMM data has enabled a dramatic increase in wide spread research of variation causes and implications.

This, together with the learnings of automotive manufacturers around the globe, is sure to have a large impact on process and product design in the years to come.

3.0 Optical Gauging at Chrysler Corporation

This chapter will provide a brief analysis of the history, organization, and use of OCMMs at Warren Truck Assembly Plant (WTAP) and Jefferson North Assembly Plant (JNAP). Analysis of WTAP will highlight the inherent barriers to OCMM use that are present due to WTAP's process complexity, work rules, organizational structure, and OCMM design. Whereas, analysis of JNAP will highlight the inherent advantages that have facilitated JNAP's success with OCMMs. These two sites give clear evidence of the impact of effective organizational and technological design on the success of OCMM systems.

This chapter will conclude with a brief benchmarking section in order to provide some insight into OCMM use at other automotive manufacturers.

3.1 Introduction to Warren Truck Assembly Plant (WTAP)

WTAP's ineffective use of OCMMs has been due in large part to the organizational and technological complexities at the plant. This section will detail many of those complexities by providing background information about WTAP and their use of optical gauging.

3.1.1 Product and History

WTAP, located in Warren, Michigan near the border of Detroit, has been building trucks since 1938 and is very typical of most older U.S. automotive plants. WTAP employs about 3,000 employees during two production shifts and is known for its aging and high seniority work force. Currently WTAP is home to the Dodge Ram pick-up truck (standard cab only) and the Dodge Dakota pick-up truck (standard and extended cab). The Ram accounts for about 75% of total production and the plant runs at an average line speed of about 72 jobs/hour.

As is typical of most assembly plants, WTAP is divided into three primary manufacturing centers- body shop, paint shop, and general assembly (also called trim, chassis, final). Because the primary focus of OCMM use is in the body shop, the remainder of this paper will focus on activities in the body shop.

3.1.2 The Body Shop at WTAP

Figure 8. visually depicts the process flow in WTAP's body shop. The two primary outputs of the body shop are the cab assembly, which is built in two stages, and the box assembly. Both the boxes and cabs are built separately and then mated before entering the paint shop. During the basic production sequence, the cabs and boxes are first built-up, then framed, and finally re-spotted. In the build-up phase, components are loosely assembled to form complete assemblies. In the framer, these assemblies are locked into position and welded in a few critical positions (less than a hundred) in order to insure dimension stability. Finally, the assembly goes through an automated re-spot (ARS) line in which additional welds (several hundred or thousand) are added for strength and stability. The OCMMs at WTAP are located at the end of these ARS lines.

In Figure 8., the parallel and sequential nature of the assembly process at WTAP is depicted. This series of dedicated and flexible assembly stages is necessary due to the three different vehicle models that WTAP produces (three different cabs- Ram, Dakota, and Dakota Extended; four different boxes- Ram 6ft., Ram 8ft., Dakota 6ft., and Dakota 8ft.). Although not readily apparent from this simple diagram, the body shop at WTAP is one of the most complex (in terms of tooling and conveyor sequencing) and flexible body shops in the world due to the multiple models produced. However, this flexibility has its drawbacks because:

- tooling must be designed to accommodate multiple models and options
- on dedicated operations like framing, vehicles must be separated and then re-sequenced
- cabs and boxes are built separately and must be merged in sequence near the end of the body shop.

Not only does this complexity make process design more complicated, but it also significantly increases the difficulty of isolating and understanding process and product problems. And because this is the central goal of variation reduction, analysis of OCMM data at WTAP can be extremely difficult.

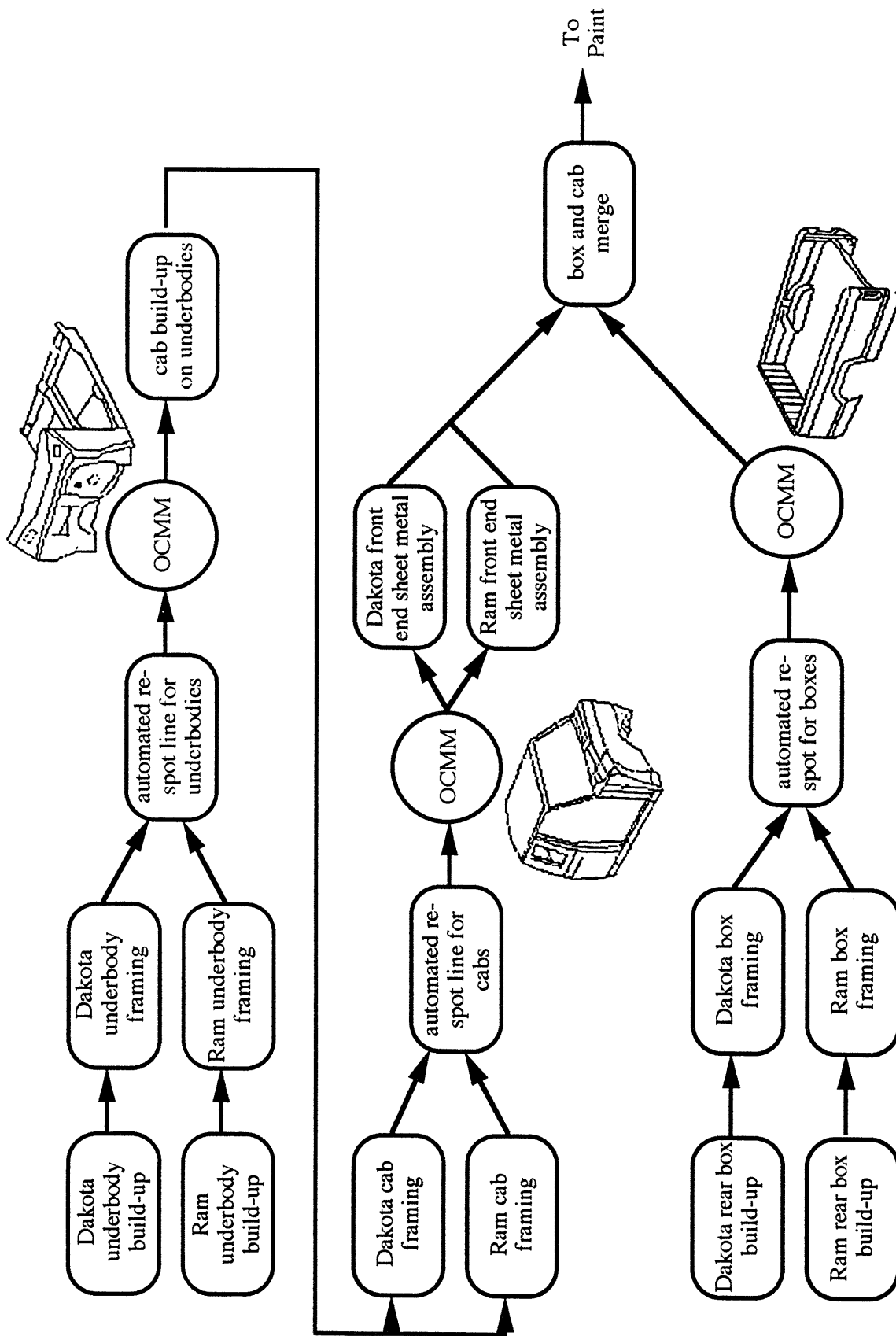


Figure 8. Process Flow Diagram for WTAP

Currently, WTAP has one of the most extensive and expensive arrangements of dimensional control devices within Chrysler. WTAP has three OCMM stations to measure underbodies, cabs, and boxes; one in-line HSCMM to measure the flush and gap of cabs and boxes at the end of body shop; two off-line dual arm CMMs; and one off-line single arm CMM to measure cabs and component assemblies.

WTAP's three Perceptron OCMM gauging stations are shown in Figure 8. The three stations are each located at the end of ARS lines and provide the capability to measure the complete underbody assembly, the complete cab assembly, and the complete box assembly. Because the cab station (located on ARS2) was the only functional station during my research, the remainder of this paper will focus on the cab station. Fortunately, because the other OCMM stations are identical in nearly every aspect, all learnings from the cab station can be directly applied to the box and underbody stations.

The cab station is used to measure three cab styles (Ram, Dakota, Dakota Extended). The cab station uses mechanical fixturing and therefore relies on a hydraulic lifter to lift the body and pneumatic clamps to properly lock the body down to the lifter tooling. Because of the three body styles, the cab station has seven locator pins, eight surface locators, and ten clamps. This makes the tooling in this station some of the most complex in the plant and with this complexity comes the increased likelihood of tooling problems. The box and underbody stations also use mechanical fixturing and are similarly complex.

Figure 9. shows the layout of the ARS2 line (i.e. the cab re-spot line). The ARS2 line is composed of 28 welding robots used to spot weld the cab assemblies. At the end of the ARS2 line is the OCMM. The central control panel for the ARS2 line is located above station 01 and is used by two W&R technicians to operate the conveyors, lifters and robots. This diagram points out two significant features of the ARS lines at WTAP. First, access to the OCMM is difficult because of its location on the ARS2 line. All ARS stations must be stopped before access is allowed and even then, the oily and expansive welding pit must be traversed in order to access the lifter or cameras. Second, the OCMM station is located far from the control panel, thus making routine maintenance and inspection inconvenient for those running the line.

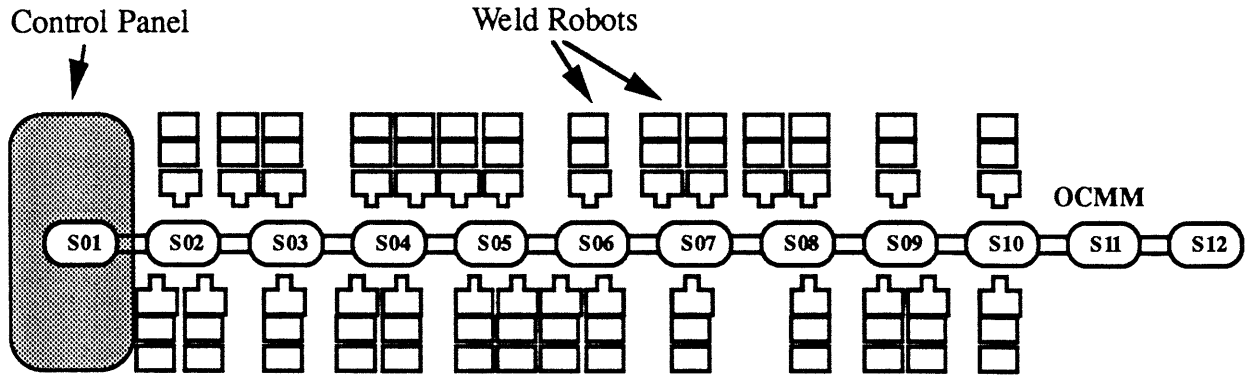


Figure 9. Automated Re-Spot Line #2 (ARS2)

In total, WTAP probably has more data gathering capability than they would ever be able to use. However, the key to dimensional control is not in gathering data, it is in using data to improve the process. And without OCMM data that can specifically track the process, process changes and adjustments are difficult to track. One reason for this difficulty is the complexity of the process at WTAP. However, the remainder of this section will discuss two other reasons- the complex work rules at WTAP and the centralized organizational structure at WTAP.

3.1.3 Work Rules

Work rules play a very important role in the utilization of OCMM equipment. The complexity of OCMM stations at WTAP necessitates that multiple disciplines are required to operate and maintain them. In a plant like WTAP that has highly specialized skilled trades, this also necessitates that many groups be involved in the repair and upkeep of these systems and that communication between these groups be effective. When this is not the case, system integrity can be compromised.

WTAP remains one of Chrysler's most traditional plants in terms of job classifications and work rules. Within the body shop at WTAP, the following skilled trades have direct involvement in OCMM maintenance and use.

toolmakers- In the skilled trades contract at WTAP, toolmakers are responsible for all tooling that is not physically attached to a weld gun. Therefore, because OCMM tooling is not attached to a welding gun, toolmakers are responsible for the build, installation, and maintenance of all OCMM tooling.

weld and repair (W&R)- The W&R have ownership of the ARS lines and are responsible for the maintenance and up-time of those lines. Because OCMMs at WTAP are located on ARS lines, the W&R control the day to day operation of the conveyor and lifter for that station. If a tooling or electrical breakdown occurs in the OCMM station, however, they cannot enter the station to fix it.

electricians- Electricians are primarily responsible for all electrical concerns in the OCMM stations. This would include the programmable logic controller (PLC) code used to control the ARS lines, proximity switches, and other electrical concerns (i.e. wiring, conduit, etc.).

layout inspectors- Layout inspectors are in charge of maintaining and operating the OCMM cameras and controller. These inspectors perform all station testing, collect all data, and insure that the OCMM is collecting data at all times.

In addition to these, tooling engineers are required to oversee all shim moves (i.e. tooling adjustments) in all stations. Two tooling engineers have responsibility for the entire body shop.

The most profound work rules that affects OCMM use at WTAP are the rules governing the W&R workers. At WTAP, the W&R have ownership of the ARS lines (i.e. they operate the lifters, repair the robots, change the weld tips, call for other trades if needed, adjust tooling, etc.). However, because the W&R only have jurisdiction over stations with welders (which the OCMM stations do not have), toolmakers and electricians must perform all maintenance in the OCMM station. This means that if a tooling or electrical problem occurs in the OCMM station, a toolmaker or electrician must be called in to repair the station. While this help is being called, the entire line must be shut down. However, because the OCMMs do not affect production and because response time is generally very slow, the OCMM station is usually by-passed (i.e. turned off so that ARS stations can operate) for significant periods of production before repairs are made. When accumulated and allowed to persist, this downtime critically limits the effectiveness of these stations.

These work rules also make quick repairs and long-lasting repairs to the OCMM station difficult because of the need to coordinate the activities of the multiple trades. Also because each group maintains only a small part of the system, no one group has total responsibility for the entire system (see Figure 10.) from either an accuracy or operations perspective. Referring back to the tolerance chain, this effectively splits up the tolerance

chain and increases the need for communication and coordination. As a result, overall system accuracy is often compromised.

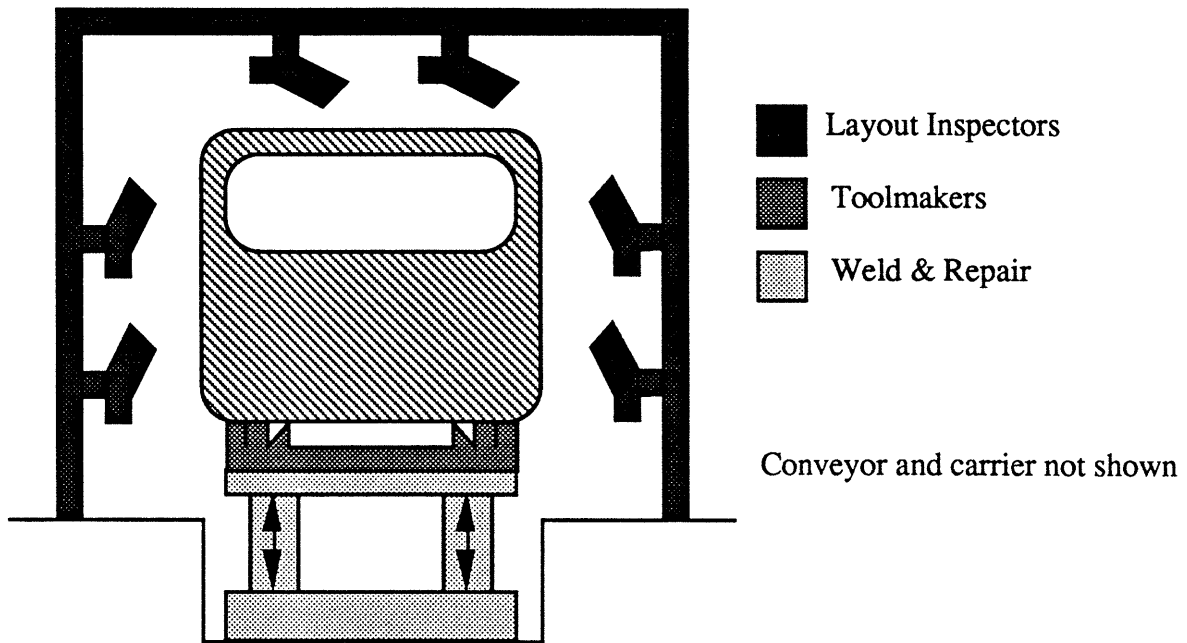


Figure 10. System Ownership of OCMMs at WTAP

In the case of the in-line HSCMM located at the end of the body shop, system ownership has been given to two dedicated layout inspectors who operate the HSCMM. As a result, the system has functioned well with only limited downtime. This approach was possible because the HSCMM was designed to operate on a spur line (explained in more detail later) rather than on an ARS line and because the layout department was able to dedicate two inspectors to the station.

3.1.4 Organizational Structure

Although attempts have been made to move to a more cross-functional organization, WTAP remains a very functionally aligned. Below is a simplified organizational chart at WTAP.

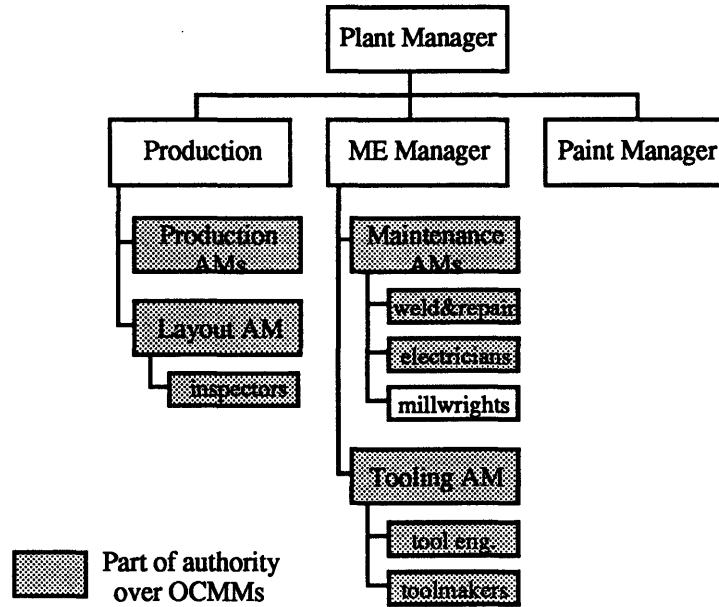


Figure 11. Traditional Organization Chart at WTAP

Traditionally, the body shop and general assembly areas of the plant have been run by the Production and Manufacturing Engineering managers. The paint shop has been separately run because of its unique and highly specialized nature. Together, these three managers have been in charge of all manufacturing operations and have been the central leaders within the plant. This structure has the advantages of centralized maintenance and production departments that can allow for better communication within the departments and more centralized expertise. However, this structure is not advantageous in the case of OCMM use.

The current structure poses several obstacles for OCMM equipment because of the coordination between the production, layout, tooling, and maintenance departments that is necessitated by work rules at the plant. The only person in the plant that has direct authority over all of these departments is the plant manager. Therefore, many small issues never get resolved between the departments and OCMM stations are often in a state of neglect because of misaligned and conflicting goals between the departments.

Recently, WTAP has attempted to transition to a new, more decentralized structure in which the Production and ME manager positions would be replaced by a body-in-white (BIW) manager, and a Trim, Chassis, & Final Manager. This would allow each of these managers to concentrate on specific areas of the plant and to have complete authority

over production, maintenance, and quality within those areas. This new organization would eliminate the involvement and coordination of both the Production and ME managers in any decision that involved production, quality, and maintenance. Within the assembly areas, however, this move has been delayed in part because of a lack of cross-functional experience for the center managers. This alone might be a career development issue that Chrysler needs to explore further.

3.1.5 OCMM Layout and Use

WTAP has been attempting to use OCMMs since 1988. Since that time, WTAP has had three different optical gauging systems in-place, each having only moderate success. WTAP has always faced accuracy problems and has never effectively used all three stations at once.

Data collection and analysis has traditionally been done by the layout department. To assist the layout department with variation reduction and analysis of OCMM data, WTAP has contracted the assistance of a "2mm Program" team. To this date, however, their effectiveness has been severely limited by the lack of OCMM data.

WTAP has made efforts to use OCMM data more effectively. However, these attempts have all been largely unsuccessful. At one time, WTAP put in place an alarm system that would stop the line if five successive defective assemblies were measured. This system was activated in an attempt to increase awareness of these systems and demonstrate the benefits of the system. Eventually, the program was stopped because it created excessive commotion and had a negative effect on line downtime. The eventual failure of this project was due in part to the lack of understanding about what dimensions to set alarms for and where to set upper and lower control limits for those dimensions. Because tolerances were set haphazardly, premature alarms were often signaled and the systems credibility was decreased. The program was also doomed because of the poor communication throughout body shop about how this program would work. Many of the workers in the shop were not even informed of the program until the first alarm went off.

With their current systems, WTAP is still a long way from implementing an alarm-based system. WTAP must first gain confidence in the use of the data by demonstrating successful process improvements. In addition, WTAP must insure that all of the operating groups within the body shop contribute to the design of this program.

Whatever the time frame for these steps, however, this type of data use must be implemented if WTAP is to fully utilize the benefits of these systems.

3.1.6 Summary of Barriers to OCMM Use at WTAP

Upon first glance, the biggest problems confronting WTAP and their use of OCMMs are:

- the communication and coordination required because of the work rules
- organizational structure which complicates communication
- the complexity of the body shop

These are significant barriers to overcome. In fact some of these barriers might need to be eliminated before OCMMs can be used at WTAP. However, this does not tell the whole story because, despite similar barriers, other plants have been able to effectively use OCMMs. The next section describes a successful installation and offers an explanation of the differences.

3.2 Introduction to Jefferson North Assembly Plant (JNAP)

JNAP is an example of the best possible environment for OCMM use. The traditional barriers seen at WTAP have been eliminated and the body shop and organization at JNAP have been designed in order to best utilize OCMMs. In order to simplify the comparison between JNAP and WTAP, this section will focus only on those areas that are significantly different at JNAP.

3.2.1 Product and History

JNAP, originally built in 1907 and completely rebuilt in 1992, has become the lead plant in Chrysler's drive to improve quality and productivity at the plant level. After being rebuilt in 1992, JNAP turned its focus toward worker teams, ergonomics, and process improvements in order to make JNAP the benchmark for excellence in manufacturing at Chrysler. Today, JNAP is home to the Jeep Grand Cherokee and can boast one the highest quality vehicles in the sport utility class (i.e. relative to other similar vehicle such as the Ford Explorer, Chevrolet Blazer, Nissan Pathfinder, etc.).

The workers at JNAP have much the same history and experiences as those at WTAP. The average age is around 51 years old and the average seniority is over 25 years. The only major difference is that most JNAP workers faced layoffs during the rebuilding of JNAP.

The body shop at JNAP is far less complex than WTAP because only one body style must be built. In addition, Chrysler did extensive benchmarking studies before building JNAP. The result is an environmentally and ergonomically friendly plant with state of the art equipment and processes. WTAP still has processes initially installed over 15 years ago.

3.2.2 Work Rules

Because JNAP has adopted a modern operating agreement (MOA) with the United Auto Workers (UAW) union, work rules and job classifications have been dramatically reduced. Within the body shop, the only skilled trades that interface with the OCMMs are the electrical technicians. The electrical technician classification combines the duties of traditional W&R and electrician classifications. These workers have complete responsibility for the operation and use of the OCMM stations (including data collection, maintenance, testing, etc.). To assist these workers, JNAP has assigned one full-time electrical technician to specialize in the OCMM stations and to assist the other electrical technicians in their use of the systems.

The flexible work rules greatly improve the operation of OCMMs at JNAP. Because electrical technicians are solely responsible for the OCMM stations, communication to other skilled trades is not required and repairs are made quickly. Therefore, the tolerance chain can be managed by one group and overall system accuracy can be better maintained. The flexible work rules also facilitate the immediate feedback of OCMM data to the process. Because the electrical technicians read the data and make changes (i.e. shim adjustments, changes in incoming material, etc.) based on the data, the involvement of tooling engineers and layout workers is eliminated. Thus, data are used much more efficiently.

3.2.3 Organizational Structure

JNAP has a much more decentralized structure than WTAP with a BIW center manager who has direct control over all BIW activities. Figure 12. gives a simplified version of this organization using job titles similar to those at WTAP.

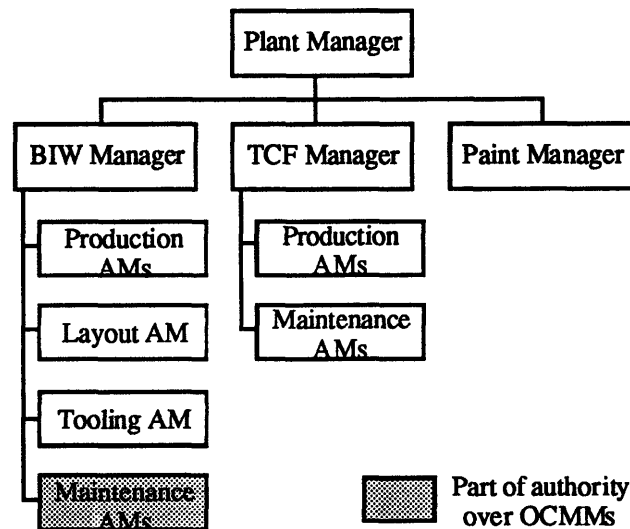


Figure 12. Simplified Organizational Structure at JNAP

This structure greatly increases the communication and coordination within the body shop by decentralizing decision making. Therefore, in BIW areas that are impacted by OCMM use such as production, maintenance, tooling, and quality, issues or concerns can be quickly resolved by the BIW manager. Communication is also aided by the colocation of all BIW offices in the center of the body shop which promotes and facilitates communication and worker interaction within the body shop.

3.2.4 OCMM Layout and Use

JNAP maintains four optical gauging stations (body complete, underbody, and side apertures- right and left). Physically, JNAP's stations are nearly identical to WTAP's with three exceptions. First, JNAP has an overhead conveyor system with individual electric motor drives for each carrier. This overhead carrier allows the carrier track to be physically separate from the station. Second, JNAP's lifters and tooling are new and less complex because they are designed for only one model. Third, JNAP's systems are

located directly after the framing operation in order to allow for quick feedback to the framing station. Because of the variation introduced in the ARS lines due to old equipment at WTAP, WTAP located their OCMMs after the ARS lines. With JNAP's new and highly accurate ARS lines, JNAP can get an accurate dimensional picture before the ARS lines.

In addition to the work rule and organizational differences already mentioned, JNAP also differs from WTAP in their use and maintenance of OCMM systems. First, JNAP has dedicated one electrical technician to oversee only OCMM use and data analysis. This person is responsible for the maintenance of all four OCMM stations and assists the electrical technicians on the line in interpreting the data and maintaining the OCMM equipment. Essentially, this person is a dedicated OCMM expert.

Second, at JNAP the line is stopped for any part with measurements outside of a pre-determined tolerance. These tolerances are established based on experience and are adjusted so that only critical defects are flagged. When the line stops, electrical technicians must retrieve the data and investigate the defect. Based on this inspection a determination is made as to the severity of the problem.

Third, two weekly meetings are held to analyze variation data. JNAP personnel from layout and maintenance together with people from the "2mm Program" analyze the data and look for process trends in order to detect problems and evaluate improvement efforts. Negative trends that could cause a series of parts to be flagged are address by these meetings along with daily analysis of the OCMM data so that a critical level is never reached.

3.2.5 Keys to JNAP's OCMM Success

To summarize, the keys to JNAP's success with their use of OCMMs can mostly be attributed to extensive planning for and commitment to OCMM use. Specific products of this planning and commitment include:

- new equipment and process
- modern operating agreement
- dedicated manpower leading to the establishment of internal expertise
- efficient organizational design

These keys are in stark contrast to the barriers present at WTAP and are strong evidence of the need for change at WTAP before OCMMs can be used successfully.

3.3 Benchmarking Other OCMM Installations

As part of this research, I have performed a very limited benchmarking study in order to assess the competitive position of Chrysler and also to learn about best practices for OCMM use. Although this study is rather limited and only touches the surface of OCMM use, it is useful in positioning Chrysler based on their OCMM use.

Ford Motor Company

I have visited two Ford plants. Ford is noted for their effective procurement of OCMMs. At Ford, OCMMs are purchased through line builders. Therefore line builders can use OCMMs to prove out the line and eliminate variation during start-up. In addition, line builders take on systems responsibility for the OCMM stations which results in a smooth hand-off to the plant. In terms of data collect and use, Ford does not significantly involve hourly workers in data collection and analysis. This job is done primarily by engineers. Ford has not had the advantage of participating in the "2mm Program".

General Motors Corporation

I have visited one GM plant. GM is noted for its intense use of data by engineers and technicians. Like Ford, hourly involvement in data collection and use is very limited. However, GM has been very effective at analyzing OCMM data and making process improvements based on that data. General Motors has also been very active in the "2mm Program".

Use in Asia

Nissan is one the few Japanese automakers to use OCMMs. Their IBAS system is a combination build and frame station with an OCMM located after it. IBAS is unique, however, because readings from the OCMM automatically adjust automated tooling points. Hyundai and Toyota also make limited use of OCMM type systems in their plants.

Use in Europe

Major European manufacturers using OCMM systems include Adam Opel, BMW, Fiat, Mercedes Benz, Saab, Volkswagen, and Volvo. Although the effectiveness of their use is unknown. The continued OCMM sales growth in Europe seems to indicate a commitment to continued OCMM use.

Chapter Three Conclusions

OCMM technology is being used throughout the automotive industry and will continue to be used. The benefits of OCMM use are clear. Installations like WTAP must therefore focus their efforts on overcoming many existing barriers to OCMM use if they hope to remain competitive in the future. Analysis clearly shows that WTAP has several inherent disadvantages to effective OCMM use when compared to JNAP. However, these disadvantages cannot be used to justify the lack of OCMM use at WTAP. Rather, they must either be removed by organizational change or circumvented by effective systems design and implementation.

Ch. 4. Implementation of Optical CMMs

The next two chapters will discuss three issues critical to the success or failure of OCMM systems: system competency, supplier relations, and management practices. In this chapter, the technical competency of OCMM systems and equipment supplier relations will be analyzed in order to develop an understanding of the current status of OCMMs at WTAP and background evidence of how this came about. The next chapter will then analyze how WTAP can learn from the past in order to create a plan for the continuous improvement of WTAP's OCMM use.

4.1 Technical Competence of OCMM Systems

This section begins with a discussion of the technical foundation of these systems in order to detail the observable technical problems that have plagued the OCMMs at WTAP. These problems, segmented into system repeatability and downtime, are well documented and provide direct evidence of problems with these systems. This section will also provide insight into possible improvements that can be made to the systems.

Because my initial focus at WTAP was to improve the repeatability and downtime problems with the ARS2 station, I spent significant time on the floor trying to address these problems so that reliable OCMM data could be gathered and used. Therefore, much of the data in this chapter comes directly from my experience and observations on the floor at WTAP.

4.1.1 System Repeatability

System repeatability of the OCMM station is defined as the ability of the system to repeatably measure the same part consistently. Effectively, it is a measure of the variation component created by the measurement system itself. Actual vehicle variation measured during production is comprised of variation from the measurement system and from the actual vehicle measured. Therefore, in order to have accurate and useful production data, this measurement variation must be minimal. In other words, system repeatability must be high.

System repeatability accounts for all variation created along the tolerance chain of the measurement system. Referring to the reference frame and tolerance chain diagrams (see

Figure 13. and Figure 14.), system repeatability would be affected by changes in any of the reference frames during the measurement of a vehicle. The most critical chains are those that comprise the camera and fixturing systems.

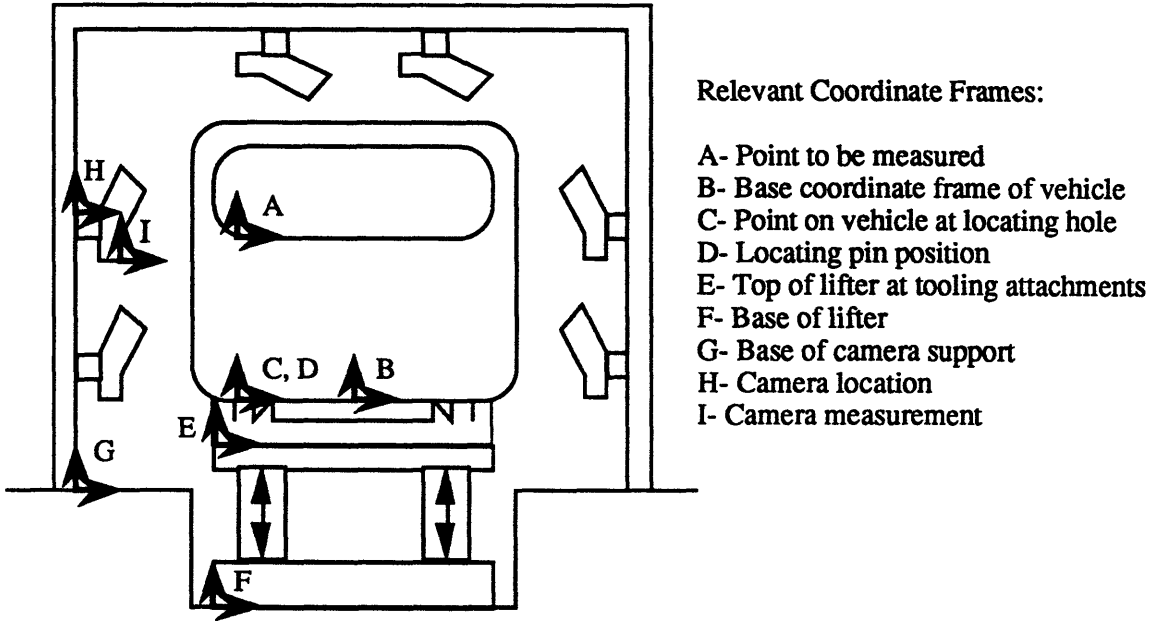


Figure 13. Relative Coordinate Frames in OCMM Station

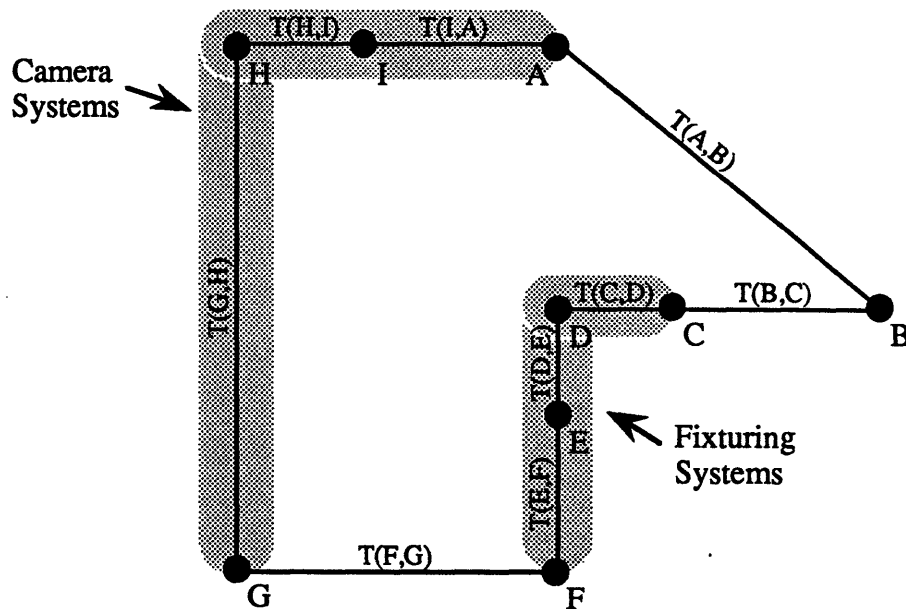


Figure 14. Tolerance Chain for OCMM Reference Frames

System repeatability also takes on added importance because in most cases the primary cause of variation in the OCMM station is also a primary cause of variation throughout the body shop. This is true because of the similarity between station design and maintenance procedures throughout the body shop. Therefore, if you understand and eliminate variation in an OCMM station, variation causes can also be eliminated throughout the assembly process. An example of this would be loose tooling. If tooling is continually becoming loose in the gauge station and is causing high variation, it is very likely that tooling is also becoming loose in other assembly stations that affect the build variation directly. Therefore, if loose tooling is a problem in the OCMM, it should also be checked in other assembly stations.

Repeatability Testing

In order to verify system repeatability, static and dynamic tests are performed in order to isolate the tolerance chains and insure total system accuracy. These tests eliminate part to part variation by measuring the same part and provide information about the causes of variation in the measurement process due to the fixturing and camera systems. It is also important to note that these tests are generally performed when the ARS lines are shut down. Therefore, vibration and contamination from other ARS stations does not affect test results.

Static testing measures the variation in the measurement process due to the camera systems. In a static test, the same part is positioned in the OCMM and is measured about fifty times without being moved. This test effectively holds $T(B,C)$, $T(C,D)$, $T(D,E)$, $T(E,F)$, and $T(F,G)$ constant so that only the variation due to $T(G,H)$, $T(H,I)$ and $T(I,A)$ is measured. Thus, a static test isolates variation caused by the camera systems- $T(G,H)T(H,I)T(I,A)$. Typically, 6-sigma static variation of about $.1\text{mm}^2$ for 95% of the measurement points is acceptable.

Dynamic testing measures the total variation in the measurement process due to all possible causes. In a dynamic test, the same part is lifted, measured, and lowered fifty times. This test measures the effect of all tolerance links. However, because $T(G,H)T(H,I)T(I,A)$ is now known from static testing and $T(B,C)T(F,G)$ is considered constant, $T(C,D)T(D,E)T(E,F)$ can be isolated. Thus, dynamic testing in combination with static testing can provide information about the repeatability of the fixturing system. Dynamic testing can also provide data on the overall system accuracy because the raw data from a dynamic test includes variation from all tolerance links. Therefore it is

critical that dynamic test results are acceptable before data is used from the OCMM. Typically, 6-sigma dynamic variation of about .25mm² for 95% of the measurement points is acceptable.

In order to further understand the variation caused by T(C,D)T(D,E)T(E,F), additional cameras were added to the OCMM station to measure the location of reference frame E, the upper lifter. By measuring the variation of that point, the lifter mechanism, T(E,F), could be isolated from the tooling and tooling-body interface, T(C,D)T(D,E).

Below is an example of the 6-sigma test results for several measurement points taken from a static and dynamic test. Other results are displayed in Appendix A.

Static Test Results					Dynamic Test Results				
SENSOR	LEFT	RIGHT	SENSOR	LIFTER	SENSOR	LEFT	RIGHT	SENSOR	LIFTER
37 I/O	0.00	0.00	LTFRT F/A	0.02	37 I/O	1.04	1.00	LTFRT F/A	0.10
37 U/D	0.02	0.02	LTFRT I/O	0.04	37 U/D	0.12	0.08	LTFRT I/O	0.04

Figure 15. Sample Static and Dynamic Test Data

In Figure 15., the 6-sigma results from six sensors are shown for a static and dynamic test, four vehicle measurement points (37 I/O Right, 37 I/O Left, 37 U/D Right, 37 U/D Left) and two lifter column measurements (LTFRT F/A, LTFRT I/O). The static test results in this example indicate that all camera systems are functioning well (6-sigma is less than .1mm² for all sensors). The dynamic test, however, indicates that sensors 37 I/O Left and 37 I/O Right are not repeatable because their 6-sigma variation is greater than .25mm². In this case, the causes for this high variation would have to be investigated and eliminated before the measurements from these sensors could be relied upon during production. The overall 6-sigma repeatability for these tests would be calculated by rank ordering the individual sensor variations and choosing the variation of the 95th percentile sensor.

Figure 16. is a summary of the dynamic and static testing that was completed at WTAP from 6/30/94 to 8/18/94.

Static and Dynamic Test Results for ARS2

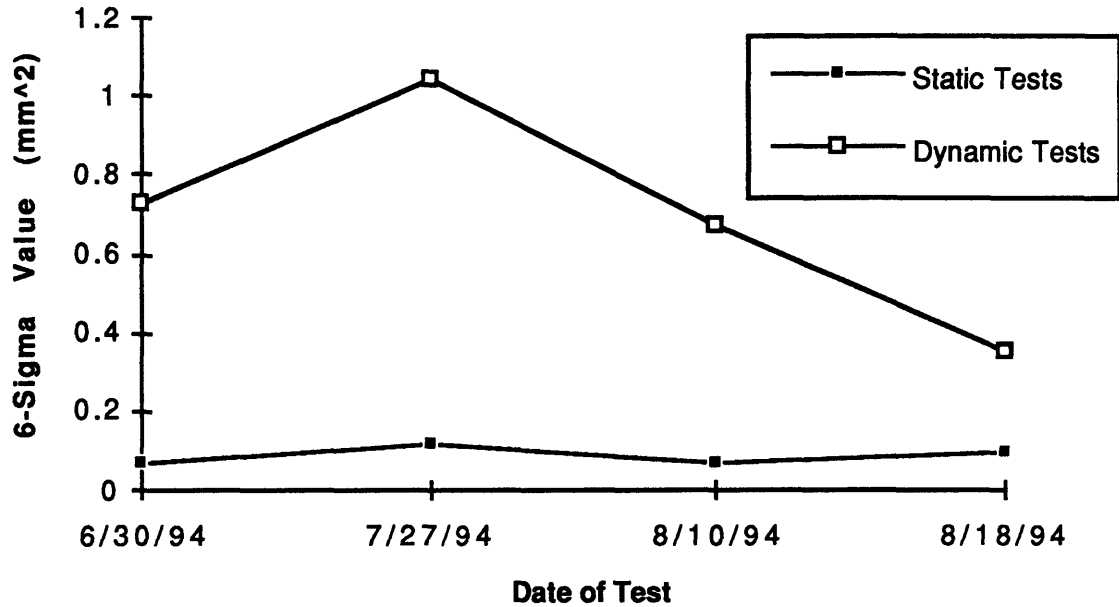


Figure 16. 6-Sigma Repeatability Tests for ARS2

Figure 16. shows the slow, yet steady, improvement of the dynamic repeatability for the ARS2 station. However, it does not show the constant battle with station downtime and tooling problems. Each time repeatability was improved, downtime or tooling problems would eliminate any improvements that had been made. For instance, on 8/18/94 repeatability tests indicated that 6-sigma repeatability was .34mm²- an acceptable repeatability to start data analysis. However, two days later a locator pin broke and repeatability was lost. By the time the pin was replaced, other tooling had come loose and all previous advancements were lost.

The periodic success that was achieved throughout this work was primarily due to the elimination of loose tooling in the OCMM station. After each test, the data were analyzed and the tooling was inspected. In most cases, the poor results were directly attributable to loose or broken tooling in the OCMM station. Ultimately, the effort to maintain repeatability was abandoned due to system and organizational level problems such as downtime (discussed in the next section) and tooling looseness.

Root Cause Analysis for Repeatability

In order to gain a better understanding of the components of variation in the OCMM station, further analysis had to be done on the components of variation. Loose tooling was obviously one primary cause. But further analysis was required to determine the root causes of the tooling variation and whether there were any other primary components to the total system variation.

Static and dynamic test data together with actual production data was used to determine the variation caused by the lifter, T(E,F). Actual production data was used to measure the effects of actual production conditions (i.e. vibration and contamination from other ARS stations) on the lifter columns when in the up position, reference point E. Analysis of this data indicated the following (see Appendix A. for raw data):

First, the lifter mechanism **was repeatable** during dynamic testing using the same body. With few exceptions, variation of the four lifter columns was less than $.1\text{mm}^2$ for dynamic tests indicating that the lifter was repeatable under testing conditions.

Second, the lifter mechanism **was not repeatable** during actual production with different bodies. When production data was analyzed, the lifter repeatability soared to over 1.0mm^2 .

Finally, the lifter mechanism's mean height was significantly different depending on body style. Therefore, the positive stops used to lock in the lifter at the up position were not effective.

Based on these results, it can be concluded that variation is caused both by the lifter, as evidenced by the production data, and the tooling, as evidenced by the dynamic testing data. Because the lifter was repeatable during dynamic testing, the poor results during dynamic testing can only be attributable to the variation introduced by the tooling and tooling-body interface, T(C,D)T(D,E). In addition, because the lifter variation was extremely high during production, the lifter mechanism itself is also contributing to variation during production, T(E,F).

Possible causes for the variation due to tooling and the tooling-body interface, T(C,D)T(D,E), include:

Loose tooling- Loose tooling affects T(D,E) by changing the location of Frame D.

Loose tooling can be caused by excessive vibration and shock due to the lifting process. Misalignment of tooling and vehicle PLPs can also cause looseness in tooling through excessive shock and vibration.

Worn tooling- Worn tooling also affects T(D,E) by changing the location of Frame D.

Worn tooling can be caused by misalignment of tooling and vehicle PLPs or delayed tooling changes.

Mis-located tooling- Mis-located tooling again affects T(D,E) by changing the

location of Frame D. Mis-located tooling can be caused by tooling movement and improper shimming during installation.

Vehicle body twist- Vehicle body twist affects T(C,D) by not allowing proper mating

between tooling and the part. PLP pins and clamps cannot accurately fixture the vehicle body when twist exists. This twist is due to variation in the assembly process.

Worn PLP locations on body- Worn PLP locations affect T(C,D) by not allowing

proper mating between tooling and the part. Worn PLP locations are caused by excessive positioning in other stations.

In order to improve these causes, WTAP must focus on improving tooling maintenance, the accuracy of the vehicle location when presented to the lifter, and the accuracy of PLP locations on the vehicle.

Possible causes for the variation of the lifter mechanism, T(E,F), during production include:

Worn or loose bearing columns- If worn, these columns cannot repeatably lift the vehicle. Thus, reference frame E is not constant between different vehicles.

Vibration effects during lifting- Vibration during lifting may cause lifter wear or lifter damage. Lifter repeatability would suffer as a result.

Vibration effects when measuring- Vibration occurring during vehicle measurement may affect the position of the vehicle or the aim of the camera systems.

Worn or ineffective positive stops on lifter- These stops will prevent repeatability if they do not provide consistent stop locations for different vehicle types.

In order to improve these causes, WTAP must consider mechanically isolating the lifter from ARS production stations, improving the positive stops, and shortening and slowing

the lifter stroke. By isolating the lifter from the ARS line, all vibration would be eliminated as a possible cause of lifter variation.

This data leads to the final conclusion that although the lifter mechanism itself may not be flawed, the design of the tooling, the physical attachment of the OCMM station to the ARS line, and poor maintenance procedures prevent these stations from obtaining and maintaining adequate repeatability. Current plans are attempting to address these issues by moving the OCMMs off the ARS line and installing new lifter systems. In addition, more effective maintenance policies are being established to insure sustained repeatability.

4.1.2 Station Up-time

Station up-time, defined here as the percentage of production vehicles measured (although not defined this way at WTAP: up-time as defined at WTAP assumes that the OCMM is repeatable when running), is as critical as the dynamic repeatability of the OCMM. The argument can be made that without repeatability, OCMM up-time is irrelevant. However, without adequate up-time, repeatability cannot be improved or maintained. Furthermore, without adequate up-time, the detection time for quality problems is increased and inspection for defects cannot be relied upon.

As previously stated, one of my primary goals during this project was to improve the up-time of the cab station. To accomplish this, I spent many hours on the ARS2 line working with the Weld&Repair technicians in order to track downtime and determine downtime causes. Despite these efforts, however, the cab station still only measured 55% of the production vehicles that went through the OCMM between mid-June, 1994 and September, 1994. Although this was an improvement over past performances, it is woefully short of the up-time required to effectively use these systems. Following is an analysis of the causes of most of this downtime.

Downtime Causes

The first step to reducing downtime is to determine its causes. These causes can then be used to determine root causes and solutions. At WTAP, I witnessed the following downtime causes during my work on the ARS2 line.

The primary cause was the electrical system failures and faults. Because of the complexity of the tooling and the multitude of moving parts, very often clamps and bad proximity switches caused the station to stop the line. When this happened, the W&R would typically by-pass the station and wait for repairs to be made at the end of the shift. These faults were also occasionally caused by mis-located parts, misshapen parts, or broken tooling that obstructed the path of the clamps.

These technical reasons for the downtime were compounded by the poor communication of problems between the maintenance shifts and the slow response time to problems. OCMM problems were rarely communicated by W&R technicians to supervision and therefore when the downtime was realized by layout inspectors, no one remembered what the problem was or when it occurred. The W&R do not maintain ownership of the tooling or electrical systems in the OCMM stations and therefore did not feel obligated to communicate OCMM problems. In many cases, there was a legitimate problem with the station. However, often the problem was just a single occurrence that would stop the line once but would not be a problem again. Because the W&R could not go into the station, they would by-pass the station in order to prevent further downtime on the line. And when problems were diagnosed, the repair time was often several days or even weeks because production equipment had priority over OCMM problems.

To illustrate these points, I will offer an example concerning downtime caused by faulty proximity switches. Proximity switches are used to signal to the PLC logic that the station is ready, done, or in process. Proximity switches are often located on clamps and movable pins in order to signal to the line that the pins and clamps are retracted before the part is moved. Failure to do this would result in broken pins and clamps and damaged vehicles. In learning about the operations of the ARS2 line, I realized that several proximity switches were by-passed in the PLC logic because the proximity switches were faulty. By by-passing the switches, faulty switches would not cause the line to stop. Therefore, instead of fixing the switches, they were by-passed to keep the line running until the switches got fixed. However, apparently no one ever knew that the switches were broken because they were never fixed. When I notified maintenance of this problem, it took over three weeks to get the problem fixed.

The reasons for downtime are clearly both technical and organizational. Until the recent plans for the improvement of these systems, however, neither had been effectively addressed by the plant or Chrysler engineering. With the latest plans for the mechanical

enhancement of these stations, recommendations for separate PLC logic and a spur line have been made to improve the up-time of these systems. Separate PLC logic will clearly simplify the detection of station errors and should decrease downtime due to problem diagnosis. However, the addition of a spur line has come under some controversy.

Spur vs. In-line

In order to address many of these downtime issues at WTAP, several suggestions have been made to install the OCMM system on a spur line (a by-pass line) so that maintenance can work on the station during production without causing downtime to the ARS lines. This would minimize downtime of the OCMM stations by allowing maintenance and tooling technicians to fix OCMM problems during production without stopping the ARS lines. Thus, repairs could be made during production when more technicians are available and the response time to OCMM problems would be greatly reduced. The in-line HSCMM at WTAP is located on spur line (due to its high cycle time) and as a result has performed very well with only limited downtime- little of which was caused by tooling or lifter problems.

There are also several disadvantages to using a spur. First, a spur is costly and would require additional floor space that may or may not be available for all ARS lines. Second, a spur could promote excessive by-passing. By providing an easy mechanism for by-passing the station, the spur might allow the W&R to by-pass the OCMM just as they are currently doing. Finally, by using this by-pass capability, WTAP will lose the ability to rely on 100% measurement for defects. This may be small price to pay now for improved OCMM use. However, if these stations will eventually be used to flag all defects in the future, 100% measurement (or as near as possible) will be required.

In the ideal case, these stations would be treated like production stations and the need for a spur would be minimized. No other assembly plants that are successful in their use of OCMMs use spurs. However, given the existing work rules and the value placed on these systems by the organization at WTAP, I believe that these systems will have a continued need for repair. Given this scenario, a spur would allow for the best utilization of OCMM. If, however, up-time for the new system can be maintained and WTAP re-negotiates work rules and station ownership, the spur could be eliminated. In this scenario, there would be occasions when production would be stopped for OCMMs and there could also be occasions when it is necessary to by-pass the station because of a catastrophic failure.

Additional Ideas to Improve Up-time

Although potentially expensive, there are also several other options that should be considered in order to improve OCMM up-time. Visual fixturing, which was discussed earlier, could effectively eliminate the downtime problems associated with the complicated tooling with the added benefit of improving dynamic repeatability. In addition, visual fixturing could eliminate the need for toolmakers and would give layout ownership of all equipment needed to insure dynamic repeatability. Thus, the number of organizations responsible for part of the tolerance chain would be reduced and communication would likely be improved.

New carriers could eliminate many of the tooling problems by improving the accuracy of the body presentation within the OCMM station. This would eliminate tool wear and frequent tooling breakages in the OCMM station and in all other ARS stations.

Finally, new work rules that would facilitate the detection and elimination of OCMM problems or dedicated manpower to track OCMM problems and serve as a system expert would also significantly improve OCMM up-time.

4.2 Equipment Supplier Relations

The analysis of equipment supplier relations can give insight into why many of the technical and organizational problems that exist at WTAP have been present since the initial installation of this equipment. Therefore, this section discusses the relationship between the supplier and buyer in an equipment purchase, specifically as it relates to OCMMs. This relationship is critical in determining and solving the technical and managerial problems in any equipment purchase because:

- 1) The relationship begins during the planning stages of equipment acquisition when changes can be made inexpensively.
- 2) Both the user and supplier have unique needs, resources, and problem solving abilities that must be communicated.
- 3) Suppliers' equipment must often be integrated with other new or existing equipment in order for the system to function properly.

There are two critical tasks that must be completed by the supplier and the original equipment manufacturer (OEM) during an equipment purchase. First, the equipment must be designed and installed so that it can function properly at the OEM site. This requires that the equipment meets desired specifications and is integrated with other equipment at the plant. Second, operators and key users must be trained to use the equipment. If both of these tasks are completed successfully, it then becomes the responsibility of the operations management to use and maintain the systems. In the case of OCMMs at WTAP, neither of the tasks was completed successfully. As a result, management at the plant was left to operate a non-capable system.

4.2.1 Equipment Specifications

The design and specification of equipment is often the most important aspect of the planning that is required for successful purchases. Equipment specifications help lay the ground work for how the system will function, how it will be used, and who will use it. Therefore, it is critical that accurate specifications be determined and that those specifications be met by the equipment suppliers.

System Responsibility

System responsibility is the responsibility for defining system level specifications and for insuring that suppliers' equipment is capable of meeting those specifications when integrated into the system. Ultimately, the success or failure of a system will depend on whether or not system level specifications are met.

The acquisition of OCMM equipment generally involves coordination between the line builder (Progressive Tool & Industries (PICO), Detroit Center Tool (DCT), etc.), the OCMM manufacturer (Perceptron), and the OEM (Chrysler, Ford, etc.). In the case of WTAP, the lifter system was already installed so no line builder was involved in the acquisition of the OCMM system.

Figure 17. visually depicts the information flow and specification levels for OCMM systems. At the highest level are the corporate goals that, for the automotive industry, are to lower vehicle cost and increase vehicle quality. To accomplish these goals, strategic level specifications (or goals) are written, one of which might be to reduce variation and scrap. If OCMM systems are selected to accomplish this goal, then system level specifications such as up-time capability for the system, accuracy of the data, and cycle

time of the system must be determined. These system level specifications then dictate what the necessary component level specifications will be.

From the analysis of this diagram, several implications are apparent. First, the path between corporate goals and equipment purchases must be clearly defined and understood by an organization. An inconsistency in this path can lead to poorly designed systems and misaligned goals within the organization. Second, there is a need for a top level integrator to insure that higher level specs can be met by the selection of lower level specs. At each level, the number of components expands and the need for control is increased. Finally, an internal knowledge base is necessary to successfully manage at each of these levels. Only through intimate knowledge of the workings of the lower specifications can the higher level specifications be accomplished.

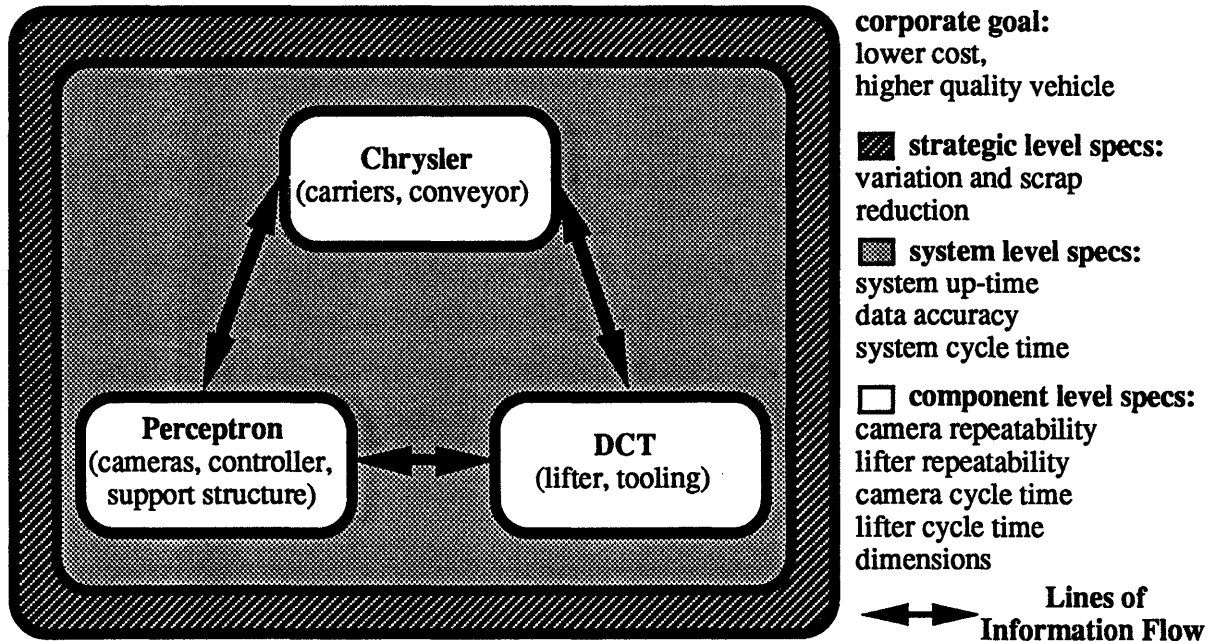


Figure 17. Equipment Specification Levels for Perceptron Systems

Supplier relations play the most important role in the determination of system and component level specs. Ultimately, the system level specs will determine the success of the system. However, the determination of realistic system and component specs often involves tremendous coordination and communication between suppliers and buyers. Therefore, specification writing is very important as a communication tool so that suppliers and buyers can work together to insure system success.

Also important is the determination of who should be the system integrator (i.e. who should have system responsibility). In most cases the buyer is in the best position because they must use the system and are most concerned with the system level output. In addition, the buyer has more at stake (before system level specs can be verified the supplier has received 90% of the contract price whereas the OEM still does not have a functioning system- see explanation of Phase I and Phase II buyoff in next section for further details) and often needs organizational learning that comes from being the system integrator.

However, in some cases the supplier is better suited to take on the role of system integrator because of their experience and intimate understanding of their product and its ideal surroundings. In addition, many OEMs no longer maintain centralized integrators. Platform teams and multiple divisions often do not effectively communicate best practices. Therefore, an experienced supplier can act as the link between successive installations. Also, many OEMs have very limited internal skill base. Lack of internal experience with a new technology can force OEMs to rely on suppliers for system design. And finally, in the attempt to become lean, many OEMs no longer have the manpower to oversee these installation programs.

In either case, however, it is important to realize that effective communications must take place between the supplier and the buyer. Because ultimately, no one knows the unique needs of the OEM as well as the OEM and no one knows the unique services and products of the supplier as well as the supplier.

Chrysler has traditionally relied heavily on its suppliers for their systems knowledge and expertise so much so that Chrysler has lost much of its internal process knowledge and must rely on vendors to provide adequate system specifications. As the low cost producer of automobiles in America, Chrysler has been able to maintain its leanness by working closely with vendors and by giving much of the systems level work to the vendors. This works well when suppliers realize this responsibility is being given to them. However, if the system responsibility is not clearly defined, the system success can be compromised, as was the case with OCMMs at WTAP.

The Specification of OCMMs at WTAP

In the case of WTAP's latest installation of OCMM equipment, system responsibility was never clearly defined and component level specifications were not met. The result was an

installation where the supplier's equipment functioned well, but the overall system did not function.

At Chrysler, the formal process of bidding and determining system and component level specifications is initiated by the OEM with a bid package that defines the suppliers requirements. Within that package, component level specifications are defined and the scope of the project is detailed. Vendors then respond to the bid package with a quote that contains costs and any additions or changes to the original bid package. After this quote is received, additional clarification can be confirmed through meetings. During installation, there are two buy-off phases. In the first buy-off phase, 90% of the quoted price is due. Phase two buy-off occurs after complete installation of the system.

Because system accuracy has been the major cause of problems with the OCMM installation at WTAP, the following analysis about specifications will focus on accuracy specifications. There are two primary system metrics that can be used to insure proper OCMM system accuracy- correlation with CMM data and system repeatability.

In the WTAP installation, Chrysler's initial bid package specifically required correlation of CMM data before phase II buyoff. However, it only required that component level accuracy specifications be met by Perceptron equipment. Specifically, the bid stated that "the contractor shall provide sensors with individual repeatability of .05 mm (3-sigma) and accuracy of .05 mm" and that "magnitude of correlation (with CMM data) to be within 1.0 mm for all measurements."⁶

In response, the Perceptron quote agreed to meet the sensor accuracy and even agreed to meet a total system accuracy of .25 mm² (6-sigma) if visual fixturing was used. However, the quote did not guarantee CMM correlation because of the common discrepancies in correlation procedure nor did it guarantee system repeatability if mechanical fixturing was used. Perceptron, however, did agree to assist WTAP in improving lifter performance if visual fixturing was not used.⁷

At the time that this quote was submitted, the decision to use mechanical fixturing had not been made. Positioning accuracy had been a continual problem for WTAP with their older systems. However, after a successful dynamic test of one of the existing lifters at

⁶ Chrysler Bid Package to Perceptron, Inc.

⁷ Perceptron proposal for installation of OCMMs at WTAP, January 25, 1994.

WTAP, the decision was made to go with mechanical fixturing. Thus, Perceptron was freed from any system level requirements in the specification sheet and was able to fulfill their component level accuracy requirements even though system accuracy was never acceptable.

In any case, Chrysler must ultimately take responsibility for failure to set systems level specifications in the first place and then for the failure of the system to meet system level specifications. A major failure was the lack of focus on the system level metrics that would ultimately insure system functioning. In the end, Chrysler incorrectly believed the system level goals had been met. However, the lack of effective testing and up-front planning led to a quick and incorrect judgment about the accuracy of the lifters. Perceptron did not take an aggressive role in insuring that system level specifications would be met by double checking the accuracy of the mechanical fixturing. Contractually it was not their obligation nor was it within the realm of their expertise.

The case of OCMMs at WTAP is clearly not representative of most equipment purchases at Chrysler or WTAP. However, it does provide a good example of what can go wrong when system level specifications are not emphasized. To contrast this case, the installation of the DEA HSCMM at WTAP is an excellent example of an effective equipment acquisition at WTAP. In 1990, WTAP contracted DEA, a European supplier of HSCMMs, to supply two mechanical CMMs to WTAP. Both of these CMMs contained new technology for WTAP (one was in-line, one had flexible fixturing) and were the first DEA machines to be installed in North America. Therefore, the stakes were high for both Chrysler and DEA because the success of these stations would likely determine whether or not future purchases would be made at Chrysler. One representative example of how DEA worked with WTAP involved vibration testing that needed to be done. DEA gave Chrysler detailed descriptions of vibration testing that needed to be completed. After Chrysler completed those tests, DEA had an independent testing agency re-perform the test (at DEA's cost) in order to verify the results. Even though both tests indicated the same result, DEA's willingness to go beyond the call of duty in this case and their commitment to up-front planning enabled the HSCMM installation to overcome many barriers presently blocking effective OCMM use. The end result was a successful system which has become a benchmark installation in North America. This level of commitment and service is more typical of what Chrysler prefers from its vendors. However, Chrysler must ultimately take responsibility for communicating this need through the project specifications.

JNAP, although using similar bidding techniques and a similar specification sheet, was able to effectively involve suppliers early in the design process and was able to design and implement a very effective system from the ground up. JNAP had the luxury of designing the system from the ground-up and involving suppliers early. In addition, their work rules and organizational design reduced the number of organizational interfaces that had to be crossed.

Ford circumvents this problem by requiring that their line builders include OCMM systems on all new lines. Thus, system responsibility is given to the line builder. Chrysler has also begun this practice with the minivan platform. This process has proven both beneficial to the line builders, who can measure their product with the OCMMs before shipping it the plants, and to the OEM's who are relieved from taking system responsibility for the OCMM systems. For new systems, this type acquisition will most likely become the wave of the future for OCMM equipment.

4.2.2 Training and On-going Support

Similar to defining specifications, coordination and communication is required in determining who should be trained, how much they should be trained, and what they should be trained to do. The quality and extent of training is critical to the long-term success of any technology purchase. In general, training is provided by the vendor in accordance with what has traditionally been required at other sites.

To insure long term system success, training must be given to all levels- from management to hourly. In addition, training must be adequate and thorough to insure that operators and managers understand both the how to use the equipment and why the equipment is being used. Therefore, it is essential that management allow time for training and that they insure that the proper users are educated.

The original goal at WTAP was to duplicate the training program used at JNAP. Because JNAP had been very effective in their implementation, it was hoped that similar training would yield the same results. Few records exist on exactly who was trained and how much training they received. However, it is fair to say that WTAP employees received far less training than JNAP employees. In addition, knowledge transfer from the "2mm Program" participants to the WTAP employees has been very limited due to the lack of

available OCMM data. Without a full-functioning system or a dedicated OCMM expert, WTAP simply could not leverage classroom training in order to sustain a steep learning curve.

Other options were also available to WTAP and still are open. Because WTAP had available internal expertise at JNAP, internal training would also have been very valuable, perhaps more so than vendor training. However, none of this was ever done, partially because of a lack of OCMM data. In the future, JNAP must become a training ground for WTAP employees.

Chapter Four Conclusions

The existing OCMM stations at WTAP are currently incapable of reliably collecting and analyzing vehicle data. In the last two chapters, two primary reasons have surfaced that help to explain why this has happened. First, the organization at WTAP, with its functional design and complex work rules, has made necessary coordination and accountability difficult to achieve. Second, a complex system design with mechanically incapable systems has made effective data collection nearly impossible. Together, these factors have led to the OCMM neglect at WTAP that has rendered WTAP's OCMM systems ineffective. Research into the root causes of repeatability and system downtime together with an analysis of the OCMM procurement at WTAP provides clear data to validate these conclusions.

Given these findings, the next step is therefore to explore management's role in the use of OCMMs at WTAP. According, the next chapter will discuss management's role in improving OCMM use at WTAP by exploring how WTAP can learn from this situation, improve the situation, and create a more effective work environment in which OCMMs can operate effectively.

Ch. 5. Learning How to Improve OCMM Use

There are many problems that have led to the poor utilization of OCMMs at WTAP. The previous chapter explained some of these problems in detail. However, it did not explain how to solve them. For that issue is ultimately up to the people at Chrysler and WTAP. This chapter details a method for enabling the creation of effective solutions to these problems and will focus on the organization at WTAP. These solutions must come from the people at WTAP and their creation will signal a culture change that will enable WTAP embrace change and adapt to changing market needs. Through a method called double-loop learning, this chapter will provide a framework that will empower the people at WTAP with the capacity to learn. With this capacity, WTAP will have the ability to improve OCMM use and resolve future problems quickly and effectively.

By using OCMM systems as an example, the focus of this approach is in questioning why problems with these OCMM systems were created in the first and why they have been allowed to persist for so many years. These are issues and questions that have seldom been asked at WTAP and may cause some discomfort because of their sensitivity. However, these are difficult issues that must be understood and overcome if WTAP is to learn from this experience and improve in the future. Creating a workforce that can provoke these issues and effectively resolve them is the ultimate goal of double-loop learning.

5.1 The Value of Organizational Analysis

One may ask what is the value in performing an organizational and cultural analysis. Why would we want to stir up these complex and often embarrassing or threatening issues. There are several reasons why such an analysis has merit. First, meaningful change must ultimately come at the cultural and organizational level- below the facades and outward behavior. The majority of problems that an organization faces on a day to day basis are merely symptoms of the deeper organizational problems and until those deeper problems are addressed, meaningful change will not occur. Second, before this change can occur, it is necessary to understand culture and assumptions that people in the culture are acting upon. Change must come about by working within cultural bounds and slowly changing assumptions about how things work. Third, different and new

perspectives bring insight to problems. Often only an outsider can help those intimately involved in a situation to see the solution.

Ultimately a culture that embraces learning and can adapt to new and innovative technology is in the best position to maintain long-term competitiveness. To do so, organizations must strive to continuously learn from past experiences and they must have a clear direction along the continuous path of change. This section will attempt to assist WTAP in this learning process and in the establishment of just such a path.

In the specific case of WTAP, cultural and organizational change will be the essential element to improving OCMM use. Effective OCMM use does require technically sound equipment, an effective implementation plan, and a supportive infrastructure. However, ultimately it is up to the people to bring about these conditions and to believe in the value of these conditions. Therefore, the cultural change is central to the successful use of OCMMs.

5.2 Double-Loop Learning- How to Improve

The traditional view of learning in most organizations is a single-loop process. An action has some result and based on that result information is fed back and actions are modified to produce intended results.

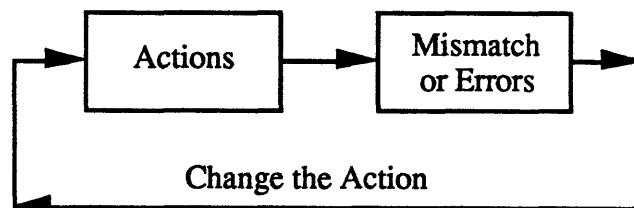


Figure 18. Single-Loop Learning⁸

Thus, single-loop learning solves the presenting problems. However, it does not help to answer the question of why the problem existed in the first place. To better understand this question, we need to develop the ability to use double-loop learning. In double-loop learning, not only is the problem considered, but the factors that created the problem in the first place are also considered. For instance, in his book "Overcoming Organizational

⁸ Argyris, Chris. Overcoming Organizational Defenses. Needham Heights, MA: Allyn and Bacon, 1990.

Defenses", Chris Argyris uses the example of a CEO retreat held in order to improve corporate-division relationships. In this example, the top level management at the retreat worked diligently to determine the problems that they saw as leading to the poor corporate-division relationships. Those problems included:

1. The philosophy and meaning of decentralization were not clear; corporate often violated divisional space.
2. Corporate staff felt that they lacked adequate authority to deal with the line.
3. Overlapping responsibilities existed among corporate staff roles.
4. Corporate staff felt that they did not have adequate contact with the CEO.

To deal with the problems the CEO charged the line staff with (1) redefining the roles in order to eliminate confusion, (2) defining adequate authority to deal with line, and (3) defining appropriate contacts for line and staff with the CEO. The task force successfully addressed these problems by re-writing the rules and policies of the corporate-staff relationship and their recommendations were implemented with only minor alterations. Thus, the presenting problems were solved.

What this approach failed to address, however, is why these problems existed in the first place. Why did the corporate staff and divisional officers adhere to, implement, and maintain these errors for so many years? These are the real issues that will continue to prevent the new rules and policies from being effective. The answer lies in organizational defenses and the inability to use double-loop learning.

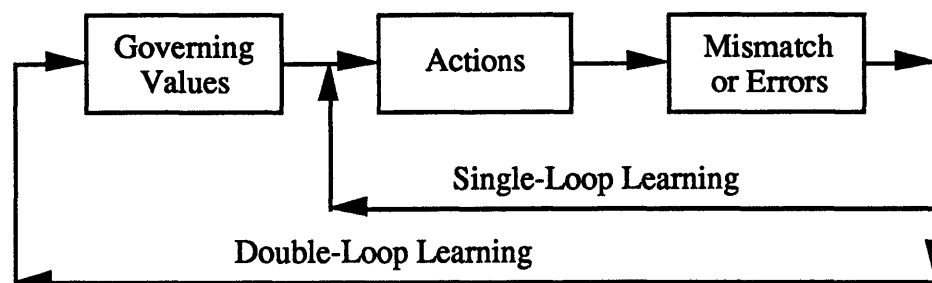


Figure 19. Double-Loop Learning⁹

Double-loop learning focuses on re-evaluating governing values when a problem occurs. It requires that an organization or individual not just solve a presenting problem, but

⁹ IBID.

rather seek to understand the fundamental values that are in conflict or leading to the problem outcome. In the case of the CEO retreat, the real issues that eventually surfaced were (1) divisional management's fear that corporate staff was making inroads on their authority, (2) corporate staff's fear that they did not wish to use their expertise because it would mean that divisional management were admitting weakness, and (3) both corporate staff and divisional presidents' playing politics to get the CEO's attention. Only when these issues were open for discussion could the real problems between corporate and divisions be solved. However, in order to bring these issues into the open, organizations must be skilled at double-loop learning and they must be in an environment that encourages this type of learning.

This model explains why when organizations create new programs and policies to address a problem, the same or slightly different problems often re-emerge to render the new programs and policies just as ineffective as the ones they replaced. Often the most difficult issues and assumptions that are at the very base of a problem are never discussed or addressed in the open for fear of creating an uproar.

So how can an organization begin to use double-loop learning. Based on his experience with many different organizations, Chris Argyris recommends the following steps in order to empower an organization with the ability to learn:

- 1) Map out how the organization currently deals with such problems.
- 2) Help the individual players diagnose the extent to which each contributes to creating and maintaining the map.
- 3) Reeducate the players to take double-loop learning from an espoused theory to a theory-in-use.
- 4) Repeat the learning experience to solve new problems.

This is a simple plan for creating the ability to double-loop learn. However, it is an incredible difficult methodology to implement that often requires professional assistance in larger organizations. However, just an awareness on the part of key individuals within an organization can be a step in the right direction.

5.3 Applying Double Loop Learning to OCMM Use at WTAP

So how then can this model be applied to OCMM use at WTAP. It would be easy to approach this from a single-loop perspective and simply determine and implement solutions for all of the problems described in this thesis. With the right focus and commitment, WTAP could probably do this in a few weeks or months. However, to really solve these problems WTAP must first understand why and how these problems were created. WTAP and Chrysler must ask why OCMM use at WTAP has been allowed to be a problem for over five years.

The immediate response for those involved will probably be to point fingers and try to escape blame. However, this is not an exercise in defining blame. Rather it must be an exercise in which people first look to understand how they have contributed to the problems that currently exist. Everyone at WTAP wants to solve the problems, why then do these problems continue to exist? In examining this question with respect to OCMM use, the people at WTAP will likely uncover many of the hidden problems that have prevented success in many other projects. Many improvements have been attempted without significant change. Now, only a change in governing values by everyone at WTAP will allow real improvement to occur. Therefore, the challenge is to bring about this change.

To achieve this change, the first requirement will be support and leadership from the top level management at WTAP. This commitment can be pushed from the lower levels or from higher levels but ultimately, those in charge at WTAP must become believers and champions. Management must create an environment in which it is all right to openly discuss problems and admit mistakes. Without this kind of environment, real learning and communication is hindered.

In addition, external help will most likely be needed. WTAP can make many improvement on their own. However, a trained facilitator not intimately involved can dramatically speed the learning process. Chrysler has recently developed some of these resources internally through the creation of the Chrysler Manufacturing College.

But this change in learning methodology is only the first step to improved OCMM use. WTAP must also set in place a plan to begin implementation. The following sections provides a framework and an initial starting point for just such a plan.

5.4 Implementing OCMM Best Practices

Given this new way of problem solving, management at all levels must then take the responsibility for promoting and facilitating the effective implementation of OCMM-based technologies. Ultimately, managers at the plant level must lead the implementation of new technology. Therefore, given the existing situation at WTAP, this section will focus on the key steps for accomplishing effective implementation and for promoting the changes that OCMM technology will necessitate.

Many past installations, like WTAP, have lacked an effective implementation strategy for gaining worker support and developing organizational commitment. Therefore, this section will attempt to provide insight into how this can be better accomplished and used to improve WTAP's current use of OCMM systems.

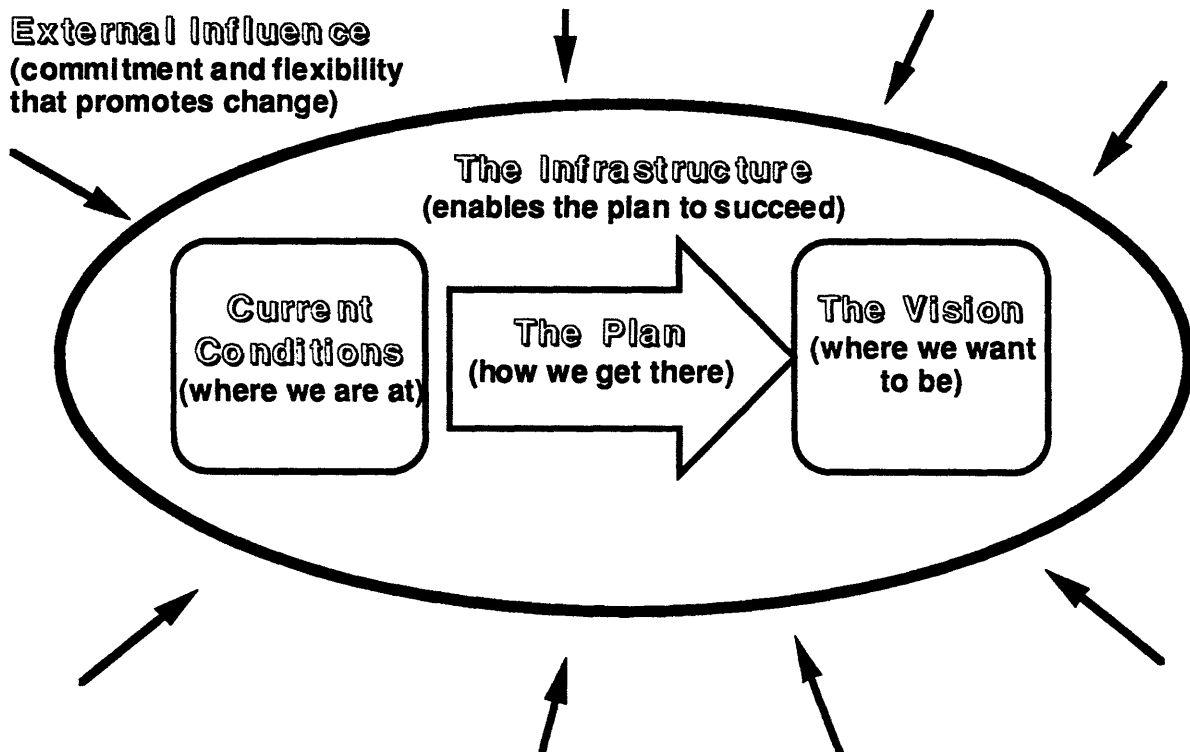


Figure 20. Conceptual Model of Change Process Needed for OCMM Improvement

As Figure 20. shows, the change process requires several key ingredients be present. First, an organization must have a good understanding of current conditions and of what

the future vision of the organization should be. Second, an organization must have a clear transition plan for making that vision a reality. Third, to facilitate the implementation and success of that plan, an appropriate infrastructure must be present. Finally, external pressures that reinforce the need for change and demonstrate commitment to change are critical. With these factors present, difficult change can be accomplished.

The existing state of OCMM use at WTAP is well documented. Therefore I will explain in more detail the other key ingredients to improving OCMM use at WTAP.

5.4.1 A Clear Vision

In-line measurement of 100% of vehicle bodies requires a shift in thinking and management must be creative in order to fully utilize this capability. Therefore, a comprehensive and thorough vision must be established that is understood by all key users at WTAP and is aligned with Chrysler's long-term objectives to improve quality, increase worker empowerment, and reduce overall manufacturing costs.

The goal of creating this vision is to effectively communicate how these systems will be used and what benefit these systems will provide to the organization. This enables the organization to develop a common understanding and direction so that the entire organization can work toward a shared long-term vision.

The vision cannot be dictated however. It must be jointly created by those who will be affected by it. Buy-in from and ownership by key systems users is critical to the long-term success of these systems. Only through key user participation can this be established.

To create this vision, WTAP must leverage its existing internal capabilities and also explore what other sites have done with OCMM equipment. Extensive benchmarking, some of which has already been completed, lays the foundation for what is possible. However, only the people of WTAP can decide what direction is the best. Therefore, the most critical question is what vision does WTAP seek to follow.

One possible vision is the operations at JNAP. WTAP is fortunate to have access to a facility like JNAP that can effectively demonstrate the benefits of these systems and bring

the long-term vision of WTAP into reality. Thus far, however, WTAP has not leveraged the learnings and advances already made at JNAP. By focusing on JNAP's use of OCMMs, WTAP can provide its workers with a concrete understanding of the goals of this change program. However, in doing this WTAP must consider what is realistic. Specifically, WTAP must consider the current organization limitations at WTAP and determine which can be eliminated and which should be circumvented. WTAP has done an very effective job of this with the DEA HSCMMs. OCMMs should be no different.

My strong belief is that WTAP should attempt to duplicate JNAP. However, this would require work rule changes and organizational changes that would require significant time and effort. WTAP would have to remain patient and committed.

5.4.2 A Plan to the Reach the Vision

WTAP must have in place a clear plan to accomplish their shared vision. This plan must consider the talents, resources, and other special requirements of the plant and be understood by all interested parties. Therefore, this plan must be created with input from all interested parties and must clearly define responsibilities in the planning and implementation process. The three pillars of that plan must include mechanical improvements to the systems, training, and data usage.

The first step in the improvement of these systems must be the redesign of the current mechanical configuration. Planning for this is already taking place. However, caution must be taken to insure that this step is not completed until other strategic decisions are made that might impact the mechanical design of the system.

The second step is the development of an effective training program that will assist the key users of this technology. Training of both managers and floor workers should be developed to eliminate current skill deficiencies so that a common understanding can be reached. To accomplish this, WTAP should make use of the existing expertise and resources available at JNAP.

The third and final step is the creation of an effective data utilization plan. This plan must detail a clear value path that will show the link between data collection, process improvements, and quality improvements. This plan should leverage existing resources at WTAP ("2mm program", process experts, etc.) and create addition resources through

cross training. Together, these resources will allow WTAP to effectively recover data and make long lasting process improvements.

5.4.3 An Infrastructure to Facilitate Implementation of the Plan

A critical element to the above plan is the establishment of an infrastructure and environment that can facilitate the implementation of a plan to improve OCMM use at WTAP. Given the current culture and environment at WTAP, even a well conceived implementation plan might fail if necessary infrastructures weren't present. By providing an infrastructure that enables commitment from all levels of management and provides accountability and support to the workers, an effective implementation plan can be successful. To accomplish this, several factors must be present.

First, accountability must be given to those in charge of implementation. Key users and those in charge of implementation must be held accountable for their results. To insure this, implementation progress should be measured and charted. Once the systems are operational, routine reports detailing system downtime, station repeatability, and overall BIW variation should be published and monitored by management at the plant.

Second, resources must be made available to those in charge of implementation. If key users and those in charge of implementation are to be held accountable for system performance, then must also be given the authority to request needed resources.

Third, recognition must also be given to those in charge of implementation. As a major change initiative, this project would require that recognition be given on a frequent basis by management at the plant and on a more infrequent basis by top-level management outside the plant (during tours or walk throughs). People need to know that their efforts are beneficial and appreciated.

Fourth, the manpower must be made available that will enable a team-based approach. OCMM data analysis requires the broad skills sets and expertise that are only achievable in a multi-functional group. In addition, those that must use this data to make changes must be involved in the analysis process. Even with the HSCMM data, this has typically not been the case.

Fifth, the existing work rules and organizational design must be modified to allow for efficient OCMM use. Without these changes, communication and coordination difficulties will continue to hinder OCMM use.

JNAP has been very effective at creating an environment that promotes the implementation and use of OCMMs. To promote the importance of OCMMs, tours by executives at JNAP often center on OCMM use, thus giving the operators recognition and acknowledgment. In addition, dedicated manpower is used to oversee OCMM use, weekly team meetings are held to analyze OCMM data, special assist devices have been built to simplify defect detection, and frequent recognition by the center manager at JNAP provides incentive for the electrical technicians.

5.4.4 Long-term Flexibility and Commitment

The pressure to continue this type of change must be applied through the commitment and support of upper level management. Implementation of new technology requires patience and often yields slow returns. However, cultural change and learning will evolve over time given the right environment and patience. Therefore, management must remain committed and must be flexible in their methodologies for facilitating change.

Increased priority and resources will be required to implement and complete a project of this magnitude. Therefore, short-term pressure for financial results will only hinder the efforts to create long-term change.

Chapter Five Conclusions

This section is purposefully short and insufficient in detail to really provide the necessary information for WTAP to understand and begin to develop the capabilities of double-loop learning. However, I hope that this brief introduction can spark some of the people to investigate this topic further. There are several excellent books about this subject and many outside resources that could help WTAP in the learning process¹⁰. However, WTAP must take initiative for implementing a methodology that will promote learning and enable long term competitiveness. OCMMs provide an ideal case study to begin implementation of such a methodology.

¹⁰ See articles by Argyris and Schein in the reference section.

Double-loop learning would only provide a framework for improving OCMM use at WTAP. Therefore, WTAP must also focus on creating an effective implementation strategy for OCMM use. WTAP must first confirm that this effort is worthwhile based on the factual performance records of other plants that use OCMMs. Next, WTAP must get input from all concerned parties and create a plan to begin implementation (this thesis is the first attempt to do this). And finally, everyone at WTAP must commit to carrying out the plan. WTAP has never developed a clear vision of how these systems would operate. Promises have been broken, and the shop floor users haven't been listened to. Therefore, the focus must be clear and mistakes must be minimized.

Ch. 6. Summary Recommendations

This chapter summarizes many of the discussions and ideas contained in the body of this thesis and provides specific recommendations for both WTAP and Chrysler. It is unlikely that review of these recommendations will result in the dramatic improvement of current challenges at WTAP and Chrysler. However, discussion and analysis of these recommendations will help to establish greater understanding of these challenges and a possible path for improvement.

6.1 Recommendations to WTAP About Their OCMM Use

Because the problems with OCMM use at WTAP have existed for such a long time, the determination and implementation of solutions will require tremendous coordination and cross-functional participation. Therefore, I have gathered input from a variety of sources in order to develop these recommendation. Ultimately, however, the men and women of WTAP must jointly develop their own solutions so that consensus and ownership in the future plans are established. Therefore, these recommendations should be useful as a guideline and initial starting point for establishing consensus and ownership at WTAP.

Based on my experience at WTAP, I believe that WTAP's OCMM systems are in need of a step improvement, not an incremental improvement. Therefore, WTAP must decide whether to continue to pursue the use of these systems with increased priority or whether to remove the systems. Half-hearted attempts to the current OCMM systems will continue to be ineffective. Given this, WTAP is faced with three options:

Option #1) Remove OCMM stations and install more in-line HSCMMs. WTAP has been tremendously effective at using in-line HSCMMs and could gather enough data to allow for variation reduction. The current OCMM systems could be removed and distributed to other Chrysler facilities in need of cameras and fixturing. This, however, would be a very costly option and might not promote data recovery and analysis by the skilled trades in charge of production equipment.

Option #2) Upgrade current systems to circumvent existing organizational barriers. Systems can be designed to eliminate current communications problems and

minimize multiple ownership. Using visual fixturing and a spur line would be examples of how to do this.

Option #3) Upgrade current systems and address existing organizational barriers.

OCMMs could be the impetus for a cultural change in the body shop that would improve work rule restrictions, worker involvement in data recovery and analysis, and quality awareness by all workers.

I believe that WTAP must commit to option #3. Strategically, Chrysler must view these systems not only based on what benefits they can provide but also in the skills that they can create within the workforce at WTAP. This creates a need to re-assess what skills they hope to develop by using these systems. I feel that the most beneficial approach would be to develop SPC skills and problems solving skills in the skilled trades workers. Therefore, the JNAP model is an appropriate model to follow.

Before this model can be achieved, however, I feel that WTAP must develop the capacity to use double-loop learning throughout the organization. WTAP must use this opportunity to learn from past problems with OCMM use and eliminate those problems in the future. With this foundation, WTAP must then:

- 1) Install competent mechanical systems- the current systems must be upgraded and moved off the ARS lines
- 2) Establish ownership and accountability- a team approach is necessary due to required skills. In addition, only through a team can accountability be given to one group.
- 3) Commit to stopping the line when necessary- WTAP will have to face some initial decrease in production in order to promote and effectively combat variation and defects.
- 4) Provide training and time for skill development- Skill development must be at the cornerstone of OCMM use. Only through properly trained users can OCMM be effectively maintained now and in the future.
- 5) Publicize results and reward workers- There must be recognition for the efforts of those people on the floor that are willing to take up the challenge.

The end goal of these efforts are to create an organization in the body shop that is focused on quality and has the skills necessary to problem solve and improve quality. OCMMs would then become just one tool to facilitate this effort.

6.2 Recommendations to Chrysler About Equipment Purchases

In order to be successful, WTAP must be provided with good product designs, capable equipment, and technical support. Therefore, I make the following suggestions to Chrysler:

Focus OCMM efforts within the confines of a well conceived top-down dimensional control plan. Successful OCMM use is highly dependent on the ability to effectively recover data, analyze data, and make improvements to product and process. Therefore, it is critical that these activities be linked through the establishment of an effective dimensional control plan that starts during design and facilitates data analysis and subsequent improvement to product and process. Without clear links between data and design, this process can be difficult and at times impossible.

Clearly identify system responsibility and focus on achieving system level specifications during equipment purchases. Whether internal or external, system responsibility must be clearly defined and communicated to all involved parties. In addition, system specifications must become the focal point of equipment acquisition and the ultimate determiner of system success. Extreme care must be taken to insure that component level specifications will enable system level specifications to be met.

Strive toward common systems (organizational design, process technology, work rules, etc.) at all manufacturing sites. Common systems facilitate knowledge transfer and help to eliminate duplicate activities. This requires that Chrysler maintain an internal knowledge base that can promote commonality among plants and can be leveraged by plants when improvements are made. Chrysler has become lean and very cost effective by outsourcing process technology. However, Chrysler must maintain enough internal expertise to facilitate effective commonality in process design between plants.

Consider projects from the perspective of the skills they will development in the organization. Installations cannot be evaluated solely based on short-term financial measures. Rather, justification must also be based on non-financial measurements with longer-term pay backs such as skill development. Installations must also focus on achieving these longer-term goals during initial design and acquisition.

Promote and facilitate double-loop learning. Double loop-learning or a similar methodology must become the backbone of a continuous improvement plan. To accomplish this, training must be provided and an environment focused on learning must be created.

Focus improvement efforts on shifting accountability and responsibility to the floor level. Listen to key system users and provide the resources that they need. In return, demand functionality and measurable improvement. Management must listen to the needs of the floor and must insure that all decisions are effectively communicated and explained to key users.

More than suggestions, these points serve as reminders of important points that facilitate effective equipment design, acquisition, implementation, and use. Chrysler's market success combined with their many outstanding manufacturing facilities is clear evidence that these suggestions have been and will continue to be a focus of Chrysler's continuous improvement efforts. Even during my short stay at Chrysler, I have seen the positive impact of these efforts. However, the case of OCMs should not be forgotten. Rather it should be used as a reminder of what can happen when these important suggestions are not followed.

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Appendix A. ARS2 Static and Dynamic Test Results

Dodge Ram

STATIC 6/30/94 6 SIGMA AT 95%= 0.07

JSN#: 263808 - 263858

Dodge Ram

DYNAMIC 6/30/94 6 SIGMA AT 95%= 0.73

JSN#: 263860 - 263910

SENSOR	LEFT	RIGHT	SENSOR	LIFTER	SENSOR	LEFT	RIGHT	SENSOR	LIFTER
37 I/O	0.00	0.01	LTFRT F/A	0.02	37 I/O	0.54	0.49	LTFRT F/A	0.14
37 U/D	0.01	0.01	LTFRT I/O	0.05	37 U/D	0.11	0.12	LTFRT I/O	0.09
35 I/O	0.04	0.10	LTFRT U/D	0.04	35 I/O	0.57	0.49	LTFRT U/D	0.08
35 U/D	0.03	0.05	LTREAR F/A	0.12	35 U/D	0.15	0.09	LTREAR F/A	0.12
38 F/A	0.02	0.18	LTREAR I/O	0.07	38 F/A	0.61	0.94	LTREAR I/O	0.07
38 I/O	0.02	0.02	LTREAR U/D	0.11	38 I/O	0.52	0.43	LTREAR U/D	0.11
39 F/A	0.01	0.02	RTREAR F/A	0.02	39 F/A	0.51	0.82	RTREAR F/A	0.14
39 I/O	0.01	0.01	RTREAR I/O	0.01	39 I/O	0.49	0.49	RTREAR I/O	0.05
7 I/O	0.01	0.01	RTREAR U/D	0.02	7 I/O	0.44	0.47	RTREAR U/D	0.04
7 U/D	0.01	0.02	RTFRT F/A	0.14	7 U/D	0.10	0.16	RTFRT F/A	0.12
6 I/O	0.01	0.02	RTFRT I/O	0.14	6 I/O	0.29	0.30	RTFRT I/O	0.18
6 U/D	0.01	0.04	RTFRT U/D	0.12	6 U/D	0.14	0.12	RTFRT U/D	0.17
3 F/A	0.05	0.06			3 F/A	0.48	0.70		
3 I/O	0.01	0.01			3 I/O	0.28	0.29		
3 U/D	0.06	0.07			3 U/D	0.14	0.15		
2 F/A	0.02	0.01			2 F/A	0.39	0.73		
2 I/O	0.02	0.01			2 I/O	0.23	0.35		
2 U/D	0.02	0.02			2 U/D	0.21	0.11		
44 F/A	0.01	0.01			44 F/A	0.19	0.27		
44 I/O	0.01	0.02			44 I/O	0.27	0.27		
44 U/D	0.01	0.01			44 U/D	0.24	0.34		
34 F/A	0.00	0.01			34 F/A	0.43	0.64		
34 U/D	0.02	0.01			34 U/D	0.17	0.13		
40 I/O	0.01	0.02			40 I/O	0.33	0.38		
40 U/D	0.01	0.01			40 U/D	0.13	0.18		
50 F/A	0.02	0.02			50 F/A	0.48	0.69		
50 U/D	0.02	0.01			50 U/D	0.09	0.06		

all units are 6-sigma variation in mm²

Dodge Ram

STATIC 7/27/94 6 SIGMA AT 95%= 0.12

JSN#: 269736 - 269785

Dodge Ram

DYNAMIC 7/27/94 6 SIGMA AT 95%= 1.04

JSN#: 269684 - 269733

SENSOR	LEFT	RIGHT	SENSOR	LIFTER
37 I/O	0.00	0.00	LTFRT F/A	0.02
37 U/D	0.02	0.02	LTFRT I/O	0.04
35 I/O	0.00	0.20	LTFRT U/D	0.04
35 U/D	0.02	0.10	LTREAR F/A	0.00
38 F/A	0.04	0.26	LTREAR I/O	0.02
38 I/O	0.02	0.02	LTREAR U/D	0.02
39 F/A	0.00	0.02	RTREAR F/A	0.00
39 I/O	0.02	0.00	RTREAR I/O	0.02
7 I/O	0.00	0.02	RTREAR U/D	0.00
7 U/D	0.00	0.08	RTFRT F/A	0.14
6 I/O	0.00	0.02	RTFRT I/O	0.14
6 U/D	0.02	0.00	RTFRT U/D	0.14
3 F/A	0.04	0.02		
3 I/O	0.02	0.02		
3 U/D	0.06	0.08		
2 F/A	0.02	0.02		
2 I/O	0.02	0.02		
2 U/D	0.00	0.02		
44 F/A	0.00	0.02		
44 I/O	0.00	0.00		
44 U/D	0.00	0.01		
34 F/A	N/A	0.02		
34 U/D	N/A	0.02		
40 I/O	0.00	0.02		
40 U/D	0.00	0.00		
50 F/A	0.02	0.02		
50 U/D	0.02	0.00		

SENSOR	LEFT	RIGHT	SENSOR	LIFTER
37 I/O	1.04	1.00	LTFRT F/A	0.10
37 U/D	0.12	0.08	LTFRT I/O	0.04
35 I/O	1.08	1.02	LTFRT U/D	0.06
35 U/D	0.10	0.14	LTREAR F/A	0.02
38 F/A	0.32	0.88	LTREAR I/O	0.04
38 I/O	0.84	0.92	LTREAR U/D	0.04
39 F/A	0.26	1.10	RTREAR F/A	0.02
39 I/O	0.94	0.86	RTREAR I/O	0.06
7 I/O	0.76	0.78	RTREAR U/D	0.04
7 U/D	0.14	0.06	RTFRT F/A	0.14
6 I/O	0.30	0.30	RTFRT I/O	0.15
6 U/D	0.32	0.28	RTFRT U/D	0.14
3 F/A	0.24	0.94		
3 I/O	0.10	0.10		
3 U/D	0.32	0.18		
2 F/A	0.14	1.04		
2 I/O	0.12	0.14		
2 U/D	0.30	0.34		
44 F/A	0.14	0.24		
44 I/O	0.38	0.22		
44 U/D	0.08	0.42		
34 F/A	N/A	0.72		
34 U/D	N/A	0.12		
40 I/O	0.48	0.70		
40 U/D	0.20	0.14		
50 F/A	0.18	0.86		
50 U/D	0.12	0.12		

all units are 6-sigma variation in mm^2

Dakota Extended Cab

STATIC 8/9/94 6 SIGMA AT 95%= 0.19
 JSN#: 273826 - 273877

Dakota Extended Cab

DYNAMIC 8/9/94 6 SIGMA AT 95%= 0.79
 JSN#: 273878 - 273928

SENSOR	LEFT	RIGHT	SENSOR	LIFTER
25 I/O	0.15	0.02	LTFRT F/A	0.02
25 U/D	0.13	0.02	LTFRT I/O	0.04
39 I/O	0.01	0.02	LTFRT U/D	0.02
39 U/D	0.00	0.03	LTREAR F/A	0.04
41 F/A	0.02	0.19	LTREAR I/O	0.02
41 I/O	0.01	0.07	LTREAR U/D	0.02
30 F/A	0.02	0.03	RTREAR F/A	0.02
30 I/O	0.02	0.02	RTREAR I/O	0.02
32 I/O	0.01	0.13	RTREAR U/D	0.02
32 U/D	0.01	0.08	RTFRT F/A	0.26
34 I/O	0.02	0.01	RTFRT I/O	0.36
34 U/D	0.01	0.01	RTFRT U/D	0.98
38 F/A	0.01	0.01		
38 I/O	0.01	0.03		
38 U/D	0.01	0.02		
5 I/O	0.01	0.02		
5 U/D	0.01	0.02		
37 F/A	0.01	0.01		
37 I/O	0.01	0.01		
37 U/D	0.01	0.01		
21 F/A	1.73	0.05		
21 U/D	1.37	0.04		
60 F/A	0.01	0.03		
60 U/D	0.04	0.02		

SENSOR	LEFT	RIGHT	SENSOR	LIFTER
25 I/O	0.70	0.28	LTFRT F/A	0.08
25 U/D	0.40	0.09	LTFRT I/O	0.16
39 I/O	0.26	0.26	LTFRT U/D	0.12
39 U/D	0.29	0.15	LTREAR F/A	0.14
41 F/A	0.69	0.79	LTREAR I/O	0.34
41 I/O	0.35	0.32	LTREAR U/D	0.22
30 F/A	0.77	0.68	RTREAR F/A	0.08
30 I/O	0.48	0.50	RTREAR I/O	0.20
32 I/O	0.53	0.46	RTREAR U/D	0.14
32 U/D	0.22	0.15	RTFRT F/A	0.24
34 I/O	0.57	0.52	RTFRT I/O	0.48
34 U/D	0.27	0.10	RTFRT U/D	1.04
38 F/A	0.35	0.35		
38 I/O	0.49	0.24		
38 U/D	0.22	0.39		
5 I/O	0.42	0.42		
5 U/D	0.30	0.06		
37 F/A	0.26	0.37		
37 I/O	0.55	0.28		
37 U/D	0.18	0.38		
21 F/A	2.04	0.76		
21 U/D	1.43	0.18		
60 F/A	0.75	0.76		
60 U/D	0.34	0.13		

all units are 6-sigma variation in mm^2

Dodge Ram

STATIC 8/10/94 6 SIGMA AT 95%= 0.07

JSN#: 274483 - 274532

Dodge Ram

DYNAMIC 8/10/94 6 SIGMA AT 95%= 0.67

JSN#: 274533 - 274582

SENSOR	LEFT	RIGHT	SENSOR	LIFTER	SENSOR	LEFT	RIGHT	SENSOR	LIFTER
37 I/O	0.15	0.01	LTFRT F/A	0.02	37 I/O	0.24	0.25	LTFRT F/A	0.08
37 U/D	0.05	0.01	LTFRT I/O	0.04	37 U/D	0.10	0.29	LTFRT I/O	0.14
35 I/O	0.05	0.03	LTFRT U/D	0.04	35 I/O	0.23	0.26	LTFRT U/D	0.14
35 U/D	0.04	0.02	LTREAR F/A	0.06	35 U/D	0.08	0.35	LTREAR F/A	0.08
38 F/A	0.02	0.04	LTREAR I/O	0.00	38 F/A	0.36	0.82	LTREAR I/O	0.10
38 I/O	0.02	0.02	LTREAR U/D	0.00	38 I/O	0.20	0.20	LTREAR U/D	0.04
39 F/A	0.01	0.04	RTREAR F/A	0.06	39 F/A	0.16	0.59	RTREAR F/A	0.06
39 I/O	0.01	0.01	RTREAR I/O	0.02	39 I/O	0.22	0.21	RTREAR I/O	0.04
7 I/O	0.01	0.02	RTREAR U/D	0.00	7 I/O	0.22	0.29	RTREAR U/D	0.02
7 U/D	0.01	0.02	RTFRT F/A	0.14	7 U/D	0.12	0.28	RTFRT F/A	0.12
6 I/O	0.02	0.02	RTFRT I/O	0.16	6 I/O	0.25	0.41	RTFRT I/O	0.16
6 U/D	0.01	0.02	RTFRT U/D	0.20	6 U/D	0.19	0.60	RTFRT U/D	0.18
3 F/A	0.10	0.05			3 F/A	0.12	0.53		
3 I/O	0.01	0.01			3 I/O	0.28	0.45		
3 U/D	0.12	0.05			3 U/D	0.39	0.62		
2 F/A	0.44	0.02			2 F/A	0.56	0.63		
2 I/O	0.03	0.01			2 I/O	0.34	0.32		
2 U/D	1.49	0.02			2 U/D	1.67	0.67		
44 F/A	0.01	0.01			44 F/A	0.12	0.21		
44 I/O	0.01	0.02			44 I/O	0.16	0.45		
44 U/D	0.02	0.02			44 U/D	0.22	0.15		
34 F/A	0.01	0.02			34 F/A	0.59	0.66		
34 U/D	0.07	0.05			34 U/D	0.14	0.50		
40 I/O	0.06	0.03			40 I/O	0.27	0.36		
40 U/D	0.02	0.05			40 U/D	0.10	0.30		
50 F/A	0.03	0.03			50 F/A	0.35	0.55		
50 U/D	0.02	0.02			50 U/D	0.15	0.22		

all units are 6-sigma variation in mm^2

Dodge Ram

STATIC 8/12/94 6 SIGMA AT 95%= 0.15

JSN#: 276736 - 276785

SENSOR	LEFT	RIGHT	SENSOR	LIFTER
37 I/O	0.05	0.05	LTFRT F/A	N/A
37 U/D	0.03	0.02	LTFRT I/O	N/A
35 I/O	0.05	0.16	LTFRT U/D	N/A
35 U/D	0.03	0.05	LTREAR F/A	N/A
38 F/A	0.08	0.32	LTREAR I/O	N/A
38 I/O	0.06	0.07	LTREAR U/D	N/A
39 F/A	0.01	0.03	RTREAR F/A	N/A
39 I/O	0.03	0.04	RTREAR I/O	N/A
7 I/O	0.03	0.04	RTREAR U/D	N/A
7 U/D	0.03	0.03	RTFRT F/A	N/A
6 I/O	0.04	0.04	RTFRT I/O	N/A
6 U/D	0.03	0.05	RTFRT U/D	N/A
3 F/A	0.12	0.04		
3 I/O	0.04	0.08		
3 U/D	0.12	0.09		
2 F/A	0.03	0.01		
2 I/O	0.05	0.09		
2 U/D	0.11	0.04		
44 F/A	0.01	0.02		
44 I/O	0.06	0.08		
44 U/D	0.03	0.02		
34 F/A	0.01	0.01		
34 U/D	0.02	0.02		
40 I/O	0.07	0.15		
40 U/D	0.02	0.04		
50 F/A	0.03	0.03		
50 U/D	0.03	0.03		

all units are 6-sigma variation in mm^2

Dodge Ram

STATIC 8/18/94 6 SIGMA AT 95%= 0.10

JSN#: 278269 - 278318

Dodge Ram

DYNAMIC 8/18/94 6 SIGMA AT 95%= 0.35

JSN#: 278321 - 278370

SENSOR	LEFT	RIGHT	SENSOR	LIFTER
37 I/O	0.01	0.02	LTFR T F/A	N/A
37 U/D	0.01	0.01	LTFR T I/O	N/A
35 I/O	0.08	0.09	LTFR T U/D	N/A
35 U/D	0.02	0.04	LTREAR F/A	N/A
38 F/A	0.10	0.02	LTREAR I/O	N/A
38 I/O	0.02	0.02	LTREAR U/D	N/A
39 F/A	0.01	0.02	RTREAR F/A	N/A
39 I/O	0.01	0.00	RTREAR I/O	N/A
7 I/O	0.01	0.01	RTREAR U/D	N/A
7 U/D	0.01	0.01	RTFR T F/A	N/A
6 I/O	0.01	0.02	RTFR T I/O	N/A
6 U/D	0.01	0.02	RTFR T U/D	N/A
3 F/A	0.10	0.04		
3 I/O	0.01	0.01		
3 U/D	0.11	0.04		
2 F/A	0.01	0.01		
2 I/O	0.01	0.01		
2 U/D	0.03	0.03		
44 F/A	0.00	0.01		
44 I/O	0.01	0.01		
44 U/D	0.00	0.01		
34 F/A	0.01	0.01		
34 U/D	0.02	0.01		
40 I/O	0.01	0.04		
40 U/D	0.01	0.02		
50 F/A	0.01	0.03		
50 U/D	0.03	0.02		

SENSOR	LEFT	RIGHT	SENSOR	LIFTER
37 I/O	0.24	0.24	LTFR T F/A	N/A
37 U/D	0.04	0.11	LTFR T I/O	N/A
35 I/O	0.23	0.28	LTFR T U/D	N/A
35 U/D	0.08	0.08	LTREAR F/A	N/A
38 F/A	0.24	0.31	LTREAR I/O	N/A
38 I/O	0.23	0.18	LTREAR U/D	N/A
39 F/A	0.35	0.32	RTREAR F/A	N/A
39 I/O	0.20	0.16	RTREAR I/O	N/A
7 I/O	0.19	0.14	RTREAR U/D	N/A
7 U/D	0.06	0.17	RTFR T F/A	N/A
6 I/O	0.12	0.09	RTFR T I/O	N/A
6 U/D	0.11	0.28	RTFR T U/D	N/A
3 F/A	0.31	0.33		
3 I/O	0.13	0.14		
3 U/D	0.10	0.32		
2 F/A	0.27	0.28		
2 I/O	0.13	0.14		
2 U/D	0.15	0.37		
44 F/A	0.11	0.20		
44 I/O	0.13	0.15		
44 U/D	0.17	0.23		
34 F/A	0.25	0.21		
34 U/D	0.16	0.27		
40 I/O	0.19	0.35		
40 U/D	0.14	0.25		
50 F/A	0.31	0.26		
50 U/D	0.11	0.10		

all units are 6-sigma variation in mm^2

Representative Production Data for Lifter Columns

JSN#: 288535-288977

SENSOR	BR		N-EXT		N	
	6-sigma	mean	6-sigma	mean	6-sigma	mean
LTFRT F/A	0.24	0.02	0.27	1.73	0.30	1.74
LTFRT I/O	0.32	0.02	0.40	-0.34	0.38	-0.32
LTFRT U/D	0.40	0.23	0.43	0.74	0.43	0.75
LTREAR F/A	0.32	0.19	0.56	0.48	0.42	0.15
LTREAR I/O	0.95	0.14	1.11	0.17	0.67	0.29
LTREAR U/D	1.06	0.48	1.18	0.47	1.60	0.17
RTREAR F/A	0.34	0.67	0.39	0.91	1.09	0.67
RTREAR I/O	0.83	-0.04	1.02	0.99	5.56	0.30
RTREAR U/D	0.74	0.22	0.91	0.71	3.44	0.15
RTFRT F/A	0.44	-0.37	0.29	-0.08	0.76	-0.30
RTFRT I/O	0.48	0.11	0.27	0.41	2.11	0.72
RTFRT U/D	0.85	0.09	0.46	-0.06	1.24	-0.13

mean values should be zero

mean values in mm; 6-sigma values in mm²

Appendix B. OCMM Downtime Log- # of Vehicles Not Measured

DATE	Perceptron JSN tracking			ARS2 Production Counts			Total Vehicles Missed**
	START JSN	END JSN	TOTAL	1ST SHIFT	2ND SHIFT	TOTAL	
6/18/94			0	0	0	0	0
6/19/94			0	0	0	0	0
6/20/94	255125	255808	684	552	554	1106	422
6/21/94	255809	256908	1100	633	565	1198	98
6/22/94	256909	257977	1069	478	541	1019	-50
6/23/94	257978	259182	1205	588	539	1127	-78
6/24/94	259183	260169	987	532	522	1054	67
6/25/94	260170	260289	120	0	0	0	-120
6/26/94			0	0	0	0	0
6/27/94	260390	261451	1062	1138	566	1704	642
6/28/94	261452	262587	1136	544	574	1118	-18
6/29/94	262588	263798	1211	617	550	1167	-44
6/30/94	263912	265121	1210	557	605	1162	-48
7/1/94	265122	265999	878	296	561	857	-21
7/2/94			0	583	0	583	583
7/3/94			0	0	0	0	0
7/4/94			0	0	0	0	0
7/5/94			0	562	429	991	991
7/6/94	266000	266596	597	524	394	918	321
7/7/94	266597	266877	281	551	527	1078	797
7/8/94			0	92	0	92	92
7/9/94			0	0	0	0	0
7/10/94			0	0	0	0	0
7/11/94			0	0	0	0	0
7/12/94			0	0	0	0	0
7/13/94			0	0	0	0	0
7/14/94			0	0	0	0	0
7/15/94			0	0	0	0	0
7/16/94			0	0	0	0	0
7/17/94			0	0	0	0	0
7/18/94	266882	267600	719	313	405	718	-1
7/19/94	267601	268412	812	362	451	813	1
7/20/94	268413	269284	872	474	399	873	1
7/21/94	269287	269559	273	409	466	875	602
7/22/94			0	450	408	858	858
7/23/94			0	0	0	0	0
7/24/94			0	0	0	0	0
7/25/94	269560	269676	117	427	458	885	768
7/26/94			0	339	494	833	833
7/27/94	269786	270687	902	407	496	903	1
7/28/94	270688	271007	320	450	453	903	583
7/29/94			0	439	407	846	846
7/30/94			0	434	442	876	876

DATE	Perceptron JSN tracking			ARS2 Production Counts			Total Vehicles Missed**
	START JSN	END JSN	TOTAL	1ST SHIFT	2ND SHIFT	TOTAL	
7/31/94			0	0	0	0	0
8/1/94	271008	271749	742	460	512	972	230
8/2/94	271750	272147	398	469	478	947	549
8/3/94	272148	272855	708	468	464	932	224
8/4/94	272856	273332	477	429	468	897	420
8/5/94			0	460	493	953	953
8/6/94			0	0	0	0	0
8/7/94			0	0	0	0	0
8/8/94	273334	273824	491	514	527	1041	550
8/9/94	273930	274482	553	400	270	670	117
8/10/94	274585	275695	1111	573	590	1163	52
8/11/94	275696	276731	1036	472	587	1059	23
8/12/94	276786	277345	560	339	237	576	16
8/13/94	277346	277419	74	548	622	1170	1096
8/14/94	0	0	0	0	0	0	0
8/15/94	0	0	0	492	350	842	842
8/16/94	277420	277521	102	496	557	1053	951
8/17/94	277522	278267	746	564	579	1143	397
8/18/94	278371	279380	1010	536	610	1146	136
8/19/94	0	0	0	573	561	1134	1134
8/20/94	0	0	0	454	610	1064	1064
8/21/94	0	0	0	0	0	0	0
8/22/94	279384	280350	967	462	552	1014	47
8/23/94	280351	281333	983	547	567	1114	131
8/24/94	281334	281368	35	500	634	1134	1099
8/25/94	281369	281654	286	511	593	1104	818
8/26/94	281655	282681	1027	562	555	1117	90
8/27/94	282682	282683	2	557	385	942	940
8/28/94	0	0	0	0	0	0	0
8/29/94	0	0	0			0	0
8/30/94	282684	282967	284	497	576	1073	789
totals			27147			48817	21670

% of ARS2 production measured: 55.61%

* ARS2 data was found to be inaccurate at times, therefore, this data should only be used as an estimate

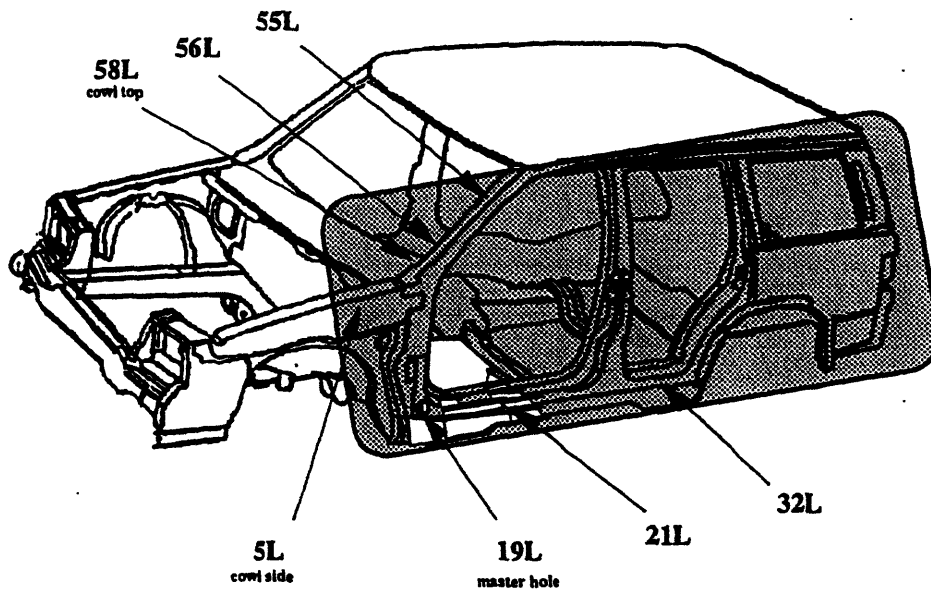
** Negative numbers indicate that testing was done on those dates

Appendix C. Sample "2mm Program" Case Studies

- **CASE I - Left Aperture H/L variation in the Body Complete**

PROBLEM IDENTIFICATION:

- Front part of the Aperture panel complete shift in the Z direction (High/Low) during framing operation.

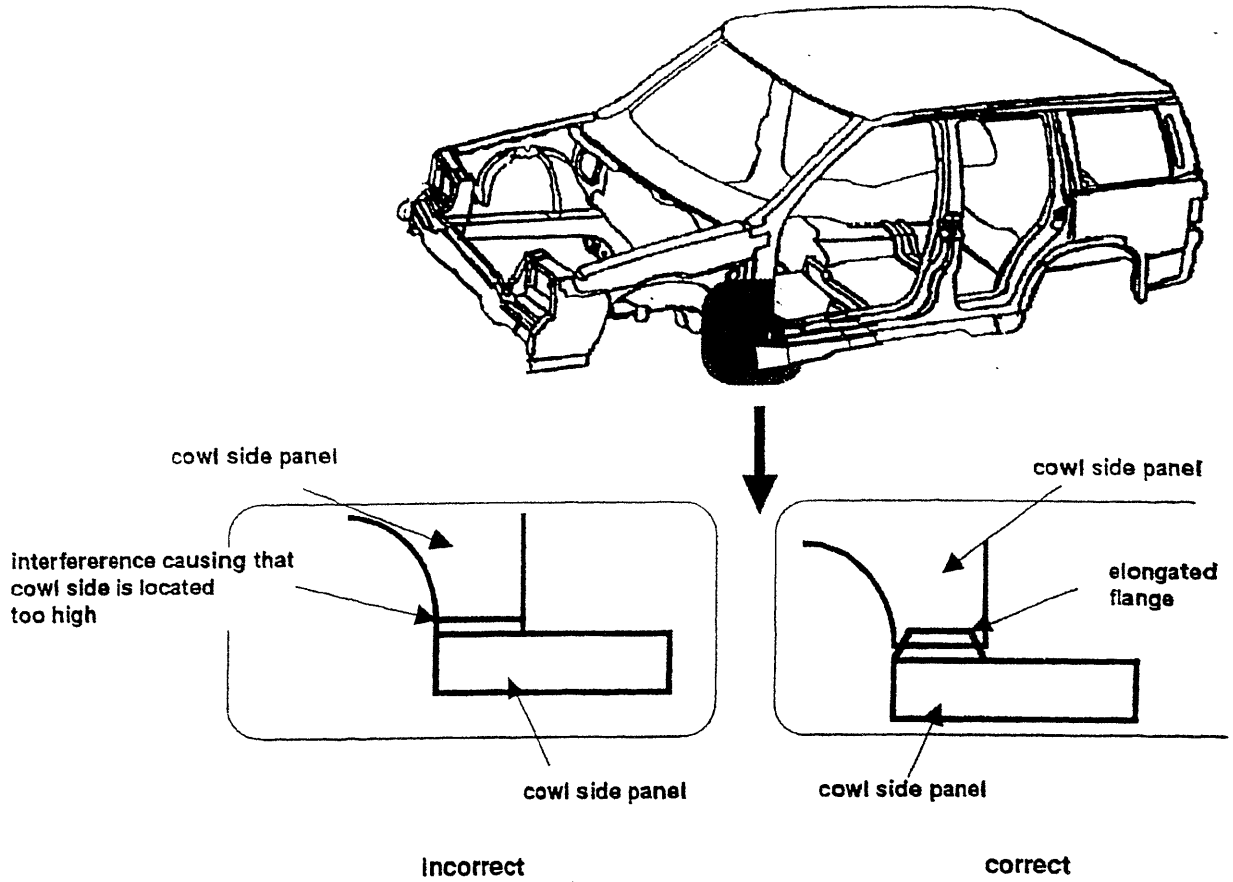


ANALYSIS:

- Interference between Cowl Side panel and Sill Body side panel caused by panel misload during loading operation in the Underbody line. Problem happened for 5% body-in-white.

CORRECTIVE ACTION

- it was suggested to change Cowl Side panel flange match with Sill Body side panel (stamping).



EVALUATION:

Problem did not happen for last 400 bodies.

VARIATION REDUCTION:

Sensor 19 shows error - out of range - when discrepancy related to the case study VII happened

<u>Sensor 2IR</u>	<u>Y</u>	<u>Z</u>	<u>SAMPLE</u>
BEFORE (01/21/92)	1.95	3.83	142
AFTER (02/13/92)	1.36	2.07	61

- **CASE X - W/House panel location variation**

PROBLEM IDENTIFICATION:

- Wheelhouse panel was misloaded in the OP-40 (Aperture line) causing deformation of the PLP hole. It happened around 15 times during first 3 weeks of Launch

ANALYSIS:

- Rough locator in the OP-40 does not protect panel against misload in the Z direction (distance between panel and wiper is 30 mm. There is no rough locator in the X direction.

CORRECTIVE ACTION:

- Rough locator was moved close to the panel controlling more precisely position of the panel in the Z direction during loading operation. It was not added rough locator in the X direction.

EVALUATION:

- Wheelhouse panel was not misloaded for last 500 panels.

<u>Sensor 116L</u>	<u>X</u>	<u>Y</u>	<u>Z</u>	<u>SAMPLE</u>
BEFORE (01/27/92)	2.10	4.69	2.02	81
AFTER (02/12/92)	1.21	1.33	1.88	106

7388-33