Development of a Tool Management System for Use in a Mass Production Metal Working Facility

by

Miles Arnone

B.S. in Mechanical Engineering
Massachusetts Institute of Technology (1991)

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

in conjunction with the
Leaders for Manufacturing Program
at the
Massachusetts Institute of Technology
May, 1993

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Abstract

Like many mass production facilities, Chrysler's Trenton Engine Plant (TEP) has become highly automated, and extensive improvements have been made over the last decade to upgrade quality control and productivity within the plant's production departments. While remarkable changes have taken place within the plant's machining and assembly departments, improvements within TEP's support departments have not kept pace with those made in the rest of the plant.

The management of tooling is an example of a support function at TEP which has evolved little over the last quarter century. While high quality tooling is essential to the production of engine parts, the development of systems to control tool quality and costs have lagged behind the institution of advanced production systems within TEP. As a result, tooling is increasingly an obstacle to the plant's plans to produce high quality products in a timely and cost effective manner.

To study this problem a system for managing tooling and tooling related information was designed and piloted. This system reduced total tooling costs through reductions in tool inventories and consumption. Savings were also realized through a reduction in the indirect costs associated with poorly managed tools, namely manufacturing scrap and machine down-time. In addition to reducing costs, the tool management system provided a feedback system which monitored tool performance

From this effort I drew two major conclusions. First, developing an effective team to develop, and institute, new manufacturing systems requires that the organizational hierarchy be dismantled locally. Participants in the pilot worked best together when the demarcations of rank that pervade factory life were blurred. Ideas were exchanged more freely, and workers took on responsibility much more willingly. Second, the tool management system we developed revealed skill deficiencies that could hinder the operation of the program in the long run, and make it difficult to institute broad-based change in the plant. The task specialization inherent in a mass production environment masks these deficiencies, but as the manufacturing environment becomes more competitive these weaknesses are being rapidly revealed

Acknowledgments

This thesis is dedicated to the men and women of the Chrysler Motor Corporation, and specifically to the people of Chrysler's Trenton Engine Plant. I had the benefit of working with people throughout the corporation and the plant who were actively pursuing a brighter future for Chrysler and American manufacturing as a whole. Without the support of these individuals this project would not have come to fruition.

In particular I would like to thank all of the participants in the TTM pilot program. These include; Larry Deszell, Bill Nichols, Jim Sammons, John Giampa, John Dorset, Joe Martin, Jim Foe, Marion Kaboesky, Larry Coffee, Frank Monaco, Chuck Burnard, Mike Stupakis, and Jim Cusic.

Thanks go out to Steve Lankford, Bill Mulhern, and Jim DeKeyser for supporting and lobbying on behalf of this project. Their active support and sponsorship of this work made it all possible.

I am grateful to Jamie Bonini for helping me to see the "big picture" when all I could see was the frustrations of the day. His drive to make Trenton Engine Plant and Chrysler world class was nothing short of inspirational.

I would also like to thank my advisors, Professors John Heywood and Alfredo Kofman of MIT. I enjoyed working with them both very much.

I gratefully acknowledge the opportunities made available to me by the Leaders for Manufacturing Program, a partnership between MIT and U.S. manufacturing companies, including the Chrysler Corporation.

Finally, this project is as much the product of Walter Durandetto's efforts as it is my own. Walter's insights, support, and guidance were invaluable throughout this project. Not only was Walter my "better half" throughout the project, but he is a good friend as well.

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APTME	Advanced Power Train Manufacturing Engineering
BTC	Block Tool Change
CNC	Computer Numerically Controlled
DM	Defective Material
ID	Internal Diameter
JIT	Just In Time
KEP	Kenosha Engine Plant
ME	Manufacturing Engineering
MOA	Modern Operating Agreement
NPICS	Non-Performance Inventory Control System
OD	Outer Diameter
PC	Personal Computer
PQI	Product Quality Initiative
SPC	Statistical Process Control
T#	Tool Number
TBI	Taken Before Inspection
TC	Team Coordinator
TEP	Trenton Engine Plant
TTM	Trenton Tool Management
UAW	United Auto Workers
WIP	Work in Process

1.0 Introduction

1.1 Trenton Engine Plant Overview: Production is Leaner, but Support Departments Lag

Trenton Engine Plant (TEP) is Chrysler's largest engine manufacturing facility, building over one million engines each year in three basic configurations, a 2.5L 4-cylinder power plant, and two V-6 engines, a 3.3L and 3.5L, both for the LH sedans. The plant will soon manufacture a fourth engine, a 2.0L four cylinder power plant.

The plant takes as input a variety of raw castings, and prefabricated components. These are then machined and assembled to create complete engines. The facility manufactures each of its three engines largely independent of the other two. For each engine type, dedicated machining and assembly departments prepare the individual components that will be brought together in final assembly. So, for example, engine blocks are manufactured in three different departments, one for each of TEP's products.

Engine manufacture has become a highly automated process. In addition to the machine tools that perform metal cutting and assembly operations, a significant investment in work-handling and transferring equipment has been made throughout the facility. Taken together, these machining, assembly, and work-handling systems are generally referred to as "transfer lines". After an engine component, like a piston, block, or head, has been loaded into the transfer line it need not be touched by human hands, problems not withstanding, until its manufacture is completed. In addition to having become highly automated, extensive improvements have been made over the last decade to upgrade quality control and productivity within the plant's 31 machining and assembly departments. In general, the plant has worked to realign its production areas along Japanese manufacturing principles, principally that of Lean Production.

While remarkable changes have taken place within the plant's machining and assembly departments, improvements within TEP's support departments have not kept pace with those made in the rest of the plant. Support departments include areas like cutter grind, the tool crib, and the engineering departments, and these areas comprise the indirect costs associated with engine manufacture. One reason for the slow rate of improvement in these areas is that well defined performance measurement systems are not in place there.

As a result, it is difficult to identify areas for improvement, or to separate good practices from poor ones.

Appropriate performance measurement systems do not exist for two reasons. First, many support departments generate products or services that are difficult to measure when compared to the large numbers of identical parts or assemblies made by production departments. Measures like "down-time" and "throughput" are not easily applied to support departments, which are organized along the lines of craft-production shops. Each support department performs a wide variety of different tasks for which establishing standard operating procedures, against which variances can be measured, is difficult if not impossible.

Second, the link between support department activities and plant performance measures is not well defined. While the poor performance of a support department like tool engineering will adversely affect the number and quality of engines the plant produces, it is more difficult to attribute a reduction in plant output to such a deficiency than it is to attribute a loss of production to a broken machine tool in a manufacturing department. Ironically, while the activities of support departments affect normally used plant performance measures indirectly, these activities have a direct impact upon actual plant performance.

1.2 Problem Statement: Tooling Costs and Quality are Sub-optimal

The management of tooling is an example of a support function at TEP which has improved little over the last quarter century. While the availability of high quality tooling is essential to the production of engine parts, the development of systems to control tool quality and costs have lagged behind the institution of advanced production equipment and systems within TEP. As a result, tooling is increasingly an obstacle to TEP's plans to produce high quality engines in a timely and cost effective manner.

In order to manufacture engines, a wide variety of regrindable and disposable tooling is used within the machining departments of TEP. When this tooling is not being used in a transfer line it falls under the care of several support departments, including the tool crib, cutter grind and tool engineering. The activities of these departments are largely uncoordinated and as a result there is no means of globally optimizing the use of tooling within the plant.

Managers within Trenton Engine Plant perceived several drawbacks of the tool management system in place at the onset of this project;

1. Tool Inventories are Excessive - Tooling is stockpiled at numerous locations. The tool crib, cutter grind department, and each machining department, as well as workers on different shifts within the same department, seek to insulate themselves from tool shortages they perceive to be caused by the activities of other departments.

2. Tool Consumption is Excessive - Machining departments consume tooling as an alternative to addressing problems related to transfer line performance, or the condition of raw materials. This results in tool shortages and machine down-time. In addition, tools are rarely changed according to a pre-set schedule, and are often left in machines beyond recommended tool change frequencies. This results in tool breakage or excessive tool wear, which reduces the number of times the tool can be reground.

3. Tool Quality is Unknown - Inadequate procedures exist for checking the quality of reground tools. The presence of large tool inventories in machining departments leads to the use of tools that should be scrapped, and the use of tools that are obsolete due to design changes. In effect, tool quality is known only after the tool is placed in the transfer line and a part is machined. Extra scrap material is produced because poor quality tools enter machine tools. Excessive downtime within machining departments is also created as a result of poor quality tooling.

1.3 Project Goal

The goal of this project was to design and pilot a system to manage tooling and tooling related information to reduce costs and drive the continuous improvement of production quality and volumes

This project consisted of an investigation of the aforementioned tooling problems and the creation of a tool management system to optimize tooling performance and costs. The system was piloted on the plant's recently installed 3.5L cylinder head line to evaluate its usefulness, and its applicability to the plant as a whole.

A quantitative study was first undertaken to better establish the characteristics of the problem as identified more generally by machining department managers. Tool costs were determined for the plant's 4 cylinder and 3.3L V-6 head lines in the following areas; tool inventories, tool consumption, lost production, and premium purchases, which are tool purchases created by an out-of-stock condition for a particular tool. These two departments were analyzed because the tool management system we developed was to be piloted on the 3.5L head line, which share many common characteristics with the other head lines, including the type of material machined (aluminum), the tools employed in the line, and the type of machining operations performed.

Once we had a clear picture of where tooling costs were being generated, a tool management system was developed to address these costs. The system we created had two primary goals:

Our first goal was to reduce total tooling costs. The Trenton Tool Management system was designed to reduce costs directly associated with tooling, such as the volume of tooling purchased and the inventory carrying costs for tooling. The system was also designed to address the indirect costs generated by poor tool management. These indirect costs, which include the cost of manufacturing scrap and machine down-time, represent a substantial part of the total cost of tooling to TEP. The tool management system addressed these costs by minimizing tool inventories and replacing inefficient means of tool distribution and control with more effective systems.

Our second goal was to create a means of continually improving tooling performance. The tool management system we developed created "stress" within the affected departments by removing safety nets, principally the inventory that allowed each department to isolate itself from the other departments which handle tooling. This stress served as an engine for continuous improvement by illuminating long-standing problems that had been hidden by excessive tool inventories, and high tool consumption.

Another mechanism for creating improvements in tooling performance was the development of an information network that provided high quality information about tool performance. This information enabled tool engineers and machining department personnel to more rationally address tool related manufacturing problems. In addition it enabled plant personnel to use tooling performance as a barometer of other conditions, including machine failures, and changes in the characteristics of machining stock.

1.4 Pilot Implementation: The importance of the "soft" story

While the development of the tool management system is important, the essence of this thesis project is the *implementation* of a cultural change within TEP. This distinction is significant because the critical issue for Chrysler, along with many American industrial firms, is not coming up with solutions to long standing problems (that's often the easy part) but rather developing means of implementing these solutions.

As a case in point, towards the end of my stay at Chrysler I learned of an effort that had been successfully carried out within TEP's gauge inspection department to rationalize the use of gauges. The system they developed possessed many of the characteristics of the tool management system we created years later, and undoubtedly faced many of the same challenges. Yet, the principals of that system had not spread to people other than those directly involved with the gauge project and no one I worked with was cognizant of how they might apply to problems other than that specifically of gauge management. The experiences associated with that effort in gauge inspection had not been leveraged into a vehicle for creating change in other areas within Chrysler as a whole, nor within the plant itself.

In light of the above I will devote significant time in this thesis to a discussion of the process by which the tool management system was implemented on the factory floor. I will make frequent use of anecdotal stories to illustrate the problems we ran into, as well as the unexpected successes we encountered. It is my feeling that an understanding of the issues faced while implementing the tool management system far outweighs the value of the tool management system itself. Only by understanding the cultural changes required to make a system like Trenton Tool Management work can the firm progress effectively towards its goals. Without such an understanding the firm will be forced to reinvent the wheel each time a substantial change in methods is sought. At best this is inefficient, and at its worst it could be fatal given today's highly competitive economic environment.

1.5 Thesis Overview

This thesis was written assuming that its audience knows little about engine manufacture, or metal working in general. The benefit of this approach is that lessons from this project can be more easily understood and applied to endeavors other than the management of tooling in a mass production setting. The down-side is that certain portions of this thesis will be laborious reading for those intimately familiar with the manufacture of engines, or mass production systems in general. So, the more knowledgeable reader may be tempted to skip over certain sections of this thesis. I urge resistance to such temptations if at all possible because exposure to a different perspective on the manufacturing process and culture at TEP may help to suspend the assumptions that interfere with the generation of new ideas. Only by questioning such assumptions can significant and lasting change be brought to any system.

This thesis is broken down into eight chapters. These chapters correspond to the chronology of the project, beginning with an overview of the manufacturing technology used in metal machining at TEP in Chapter 2. This is followed by Chapter 3, a characterization of the tool management systems in place at Trenton prior to this project. The design of a new tool management system, Trenton Tool Management, is then detailed in Chapter 4, succeeded by a discussion of the implementation of this system within a head machining department. After the results of the pilot program are presented in Chapter 6, the steps taken to expand the tool management system throughout the plant will be explained in Chapter 7. Finally, Chapter 8 presents some overarching conclusions from the project.

This thesis is written from the vantage point of the principal members of the team that developed the tool management system described here, namely Walter Durandetto and myself. Thus, when the term "we" or "our" appears it refers to Miles Arnone and Walter Durandetto. A narrative style was employed throughout the document to improve readability, and to make the document more accessible for personnel within Chrysler who might like to apply our work to other parts of Trenton Engine Plant or other manufacturing facilities.

Finally, this thesis is written from a "weakness orientation". The Trenton Engine Plant is in many respects an excellent manufacturing facility. Nonetheless, by focusing upon the plant's weaknesses, as opposed to its strengths, we felt this document would better serve its primary customers, the men and women of Trenton Engine Plant and Chrysler Motor Corporation.

2.0 Mass Production Metal Cutting

Mass production is loosely defined as the manufacture of a high volume of identical, or near-identical, parts using specialized, dedicated machinery. The advantage of such a system lies with its ability to produce a high volume of parts in a short period of time. Its principal weakness is that reconfiguring the system to manufacture different parts is difficult, and running a mass production facility to make a small numbers of parts is inefficient and costly. This inefficiency exists primarily because the capital expenditure required for mass production equipment is higher than for other production systems due to its customized nature.

Mass production in the automotive industry has been built around the concept of the transfer line. A transfer line consists of a predominantly serial arrangement of several machine tools (as few as two, and as many as 25 or more), each performing a limited set of processes upon a workpiece. Workpieces move between machines, or stations, via a transfer bar or other mechanism. A typical transfer line arrangement is illustrated in Figure 2-1. Parts enter the transfer line at the end marked 'A' and proceed, from station to station, until the completed part exits the line at 'B'. Stations are grouped into "operations", and these operations are separated by several feet of conveyors to provide room for workers to load and unload parts. This arrangement allows buffers to be built-up between groups of stations so that they can be run somewhat autonomously. Because each station depends upon the upstream stations to supply it with parts for manufacture, down-time of any station creates down-time for all stations down-stream of the affected station.

2.1 Metal Cutting Machinery

While transfer lines are used for many applications, including both machining and assembly functions, our focus is on the use of transfer lines to machine rough metal castings into finished parts. These parts are subsequently assembled into complete automotive engines. A wide variety of machining processes are employed throughout the transfer lines at TEP including milling, drilling, boring, reaming, grinding, honing, and tapping. I will now outline the key elements of transfer-line machinery as they pertain to the manufacture of engine heads. Elements of the transfer-line that pertain to tool usage and management will be highlighted as well.

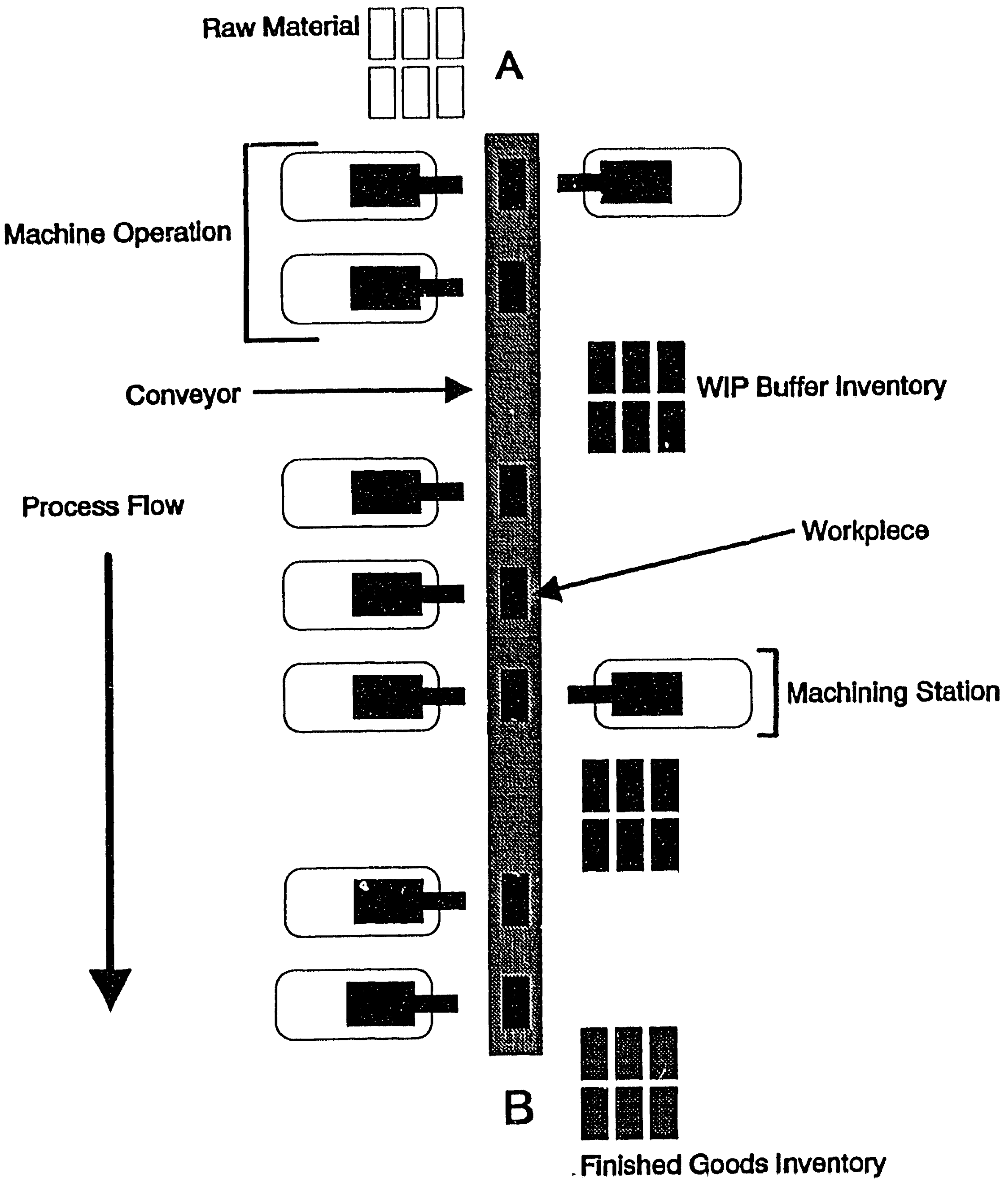


Figure 2-1: This figure illustrates a typical transfer line. The line, which consists of several operations arranged serially, is designed to produce a large volume of parts.

Machining Station

The heart of the metal-cutting transfer line is the machining station. Each station represents a machine tool in and of itself, designed to perform specific machining operations. Figure 2-2 illustrates a typical machining station. The machining head contains one or more spindles, each of which holds a cutting tool. The spindles can either be motorized or driven by a belt attached to an independent motor. Often, all of the spindles on a single machine-head are driven at the same speed by a single motor. The number of spindles found on stations in the 3.5L head machining department varies from one to as many as eighteen. Thus, up to eighteen machining operations are performed simultaneously by a single station.

Because all of the spindles are attached to a single machine-head, their motions relative to the workpiece are identical. This, along with physical constraints imposed by the use of many spindles driven by a single motor, does much to define the distribution of machining operations between each station. Other factors defining this distribution include the desired machining time at each station (the cycle time), and constraints placed upon station size and weight.

All of these constraints make it difficult to revise the characteristics of a machining process once the station has been installed. If, for example, a station performs several drilling operations using different diameter tools, it may not be possible to optimize the rate at which the tool is fed into the workpiece for each different drill, particularly if the spindles all run at the same rotational speed. This problem can be compounded further if a machining operation at this station is just the first stage in a process for which the machining is distributed over several stations as in Figure 2-3. If, for example, a downstream station proves incapable of completing the second-stage of milling a slot, the first stage of the milling operation might be altered to remove a larger amount of stock, leaving less work for successive operations. Unfortunately, this change may not be possible without degrading the performance of other machining operations on the first station and/or increasing the cycle-time beyond acceptable limits. Thus, it is difficult to design, troubleshoot, and improve the machining processes and tooling used in the transfer line because 1] many machining operations, and different processes, are performed simultaneously by a single station, and 2] a single machining operation, such as drilling a specific hole, is often distributed over multiple stations.

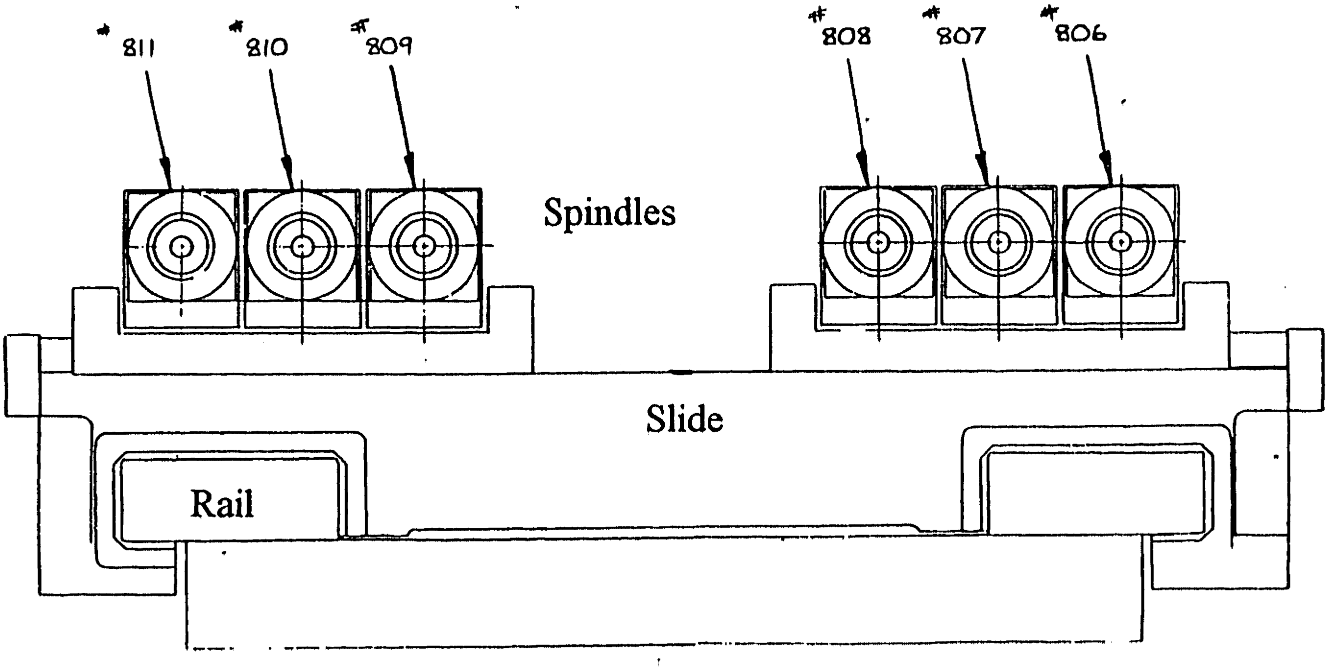


Figure 2-2: Front view of a machining station for drilling bores in an engine block. Six spindles, numbered #806 to #811, are mounted on a slide which moves along the two rails shown. These rails are in turn positioned on a wing base which is not depicted.

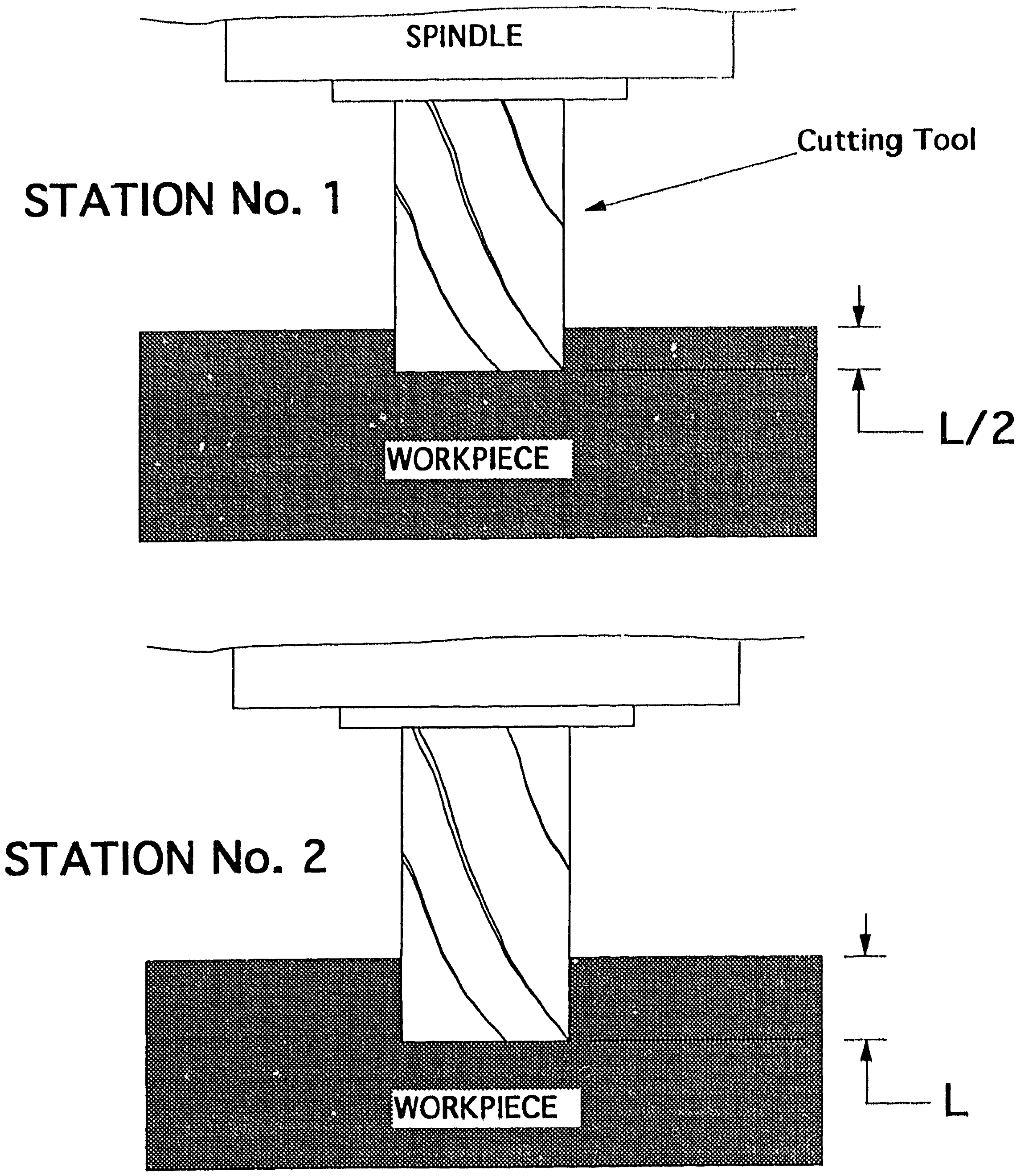


Figure 2-3: Milling operation for a slot of depth L in a single workpiece. The operation is distributed over two stations to obtain the desired cycle time for the part.

The motions of the machine-head and tooling are guided by hardened and ground cast-iron rails and driven either by hydraulic cylinders or ball screws. The speed and range of these motions are controlled using servo motors, hydraulic actuators, logic controllers, and limit switches. These drive elements, along with the machine-head, are mounted on large castings called wing-bases, which anchor the entire machine to the floor and position it relative to part transfer and fixturing equipment.

Subsidiary systems include the liquids used to lubricate the cutting tools, dissipate heat from cutting tools, and wash away debris during machining. These coolants are fed to the tool-work interface by rigid tubing. These tubes, along with the mechanisms used to interlock tools and spindles, and the proximity of the station to fixturing devices, make it difficult to access the head when a tool change is required. The machine-heads can only be drawn back from the fixtures about two feet, leaving little room for an operator to reach in, loosen a tool holder, and remove a broken or worn tool. In all cases access to tooling is only possible from the side or top of the station, rather than from the front as in stand-alone machine tools. This makes it difficult to properly remove and install tools which can weigh in excess of forty pounds.

Part Transfer Mechanisms and Fixturing

Parts are transferred between stations in the transfer-line by lift and carry mechanisms. After each machining cycle, parts must be removed from the fixtures used to locate the parts, and then moved and relocated in the fixturing at the next station. Within each operation in the transfer line all parts move simultaneously from one station to the next. In addition to moving the work-in-progress between stations, roll-over mechanisms also reorient the parts depending upon the machining operations that are to be performed at each station.

In the case of the 3.5L head line, power conveyors are used to load parts into the transfer line and free rolling conveyors are used to remove the parts from the line. Power conveyors are also used between operations. To move the parts from one fixture at a station to the next fixture, lift and carry mechanisms are used. These are necessary because the heads are commonly located using pins, onto which the parts must be dropped. For some operations these pins are not used, and the work-piece is located using one or more datum surfaces or locating pads on the part.

In addition to mechanisms used to locate the part relative to each station, additional fixturing is used to guide and support the tooling used for machining at each station. Large plates with orifices located and sized for each tool help stabilize the tool during metal cutting. These fixtures, called bushing plates, and the associated bushings which they contain, are required to prevent tools from "running-out" or buckling during machining operations at high speeds and under heavy loads. The bushing plates are located between the machine-head and the workpiece, and as the head is fed in towards the workpiece the tools pass through the bushings in the plate and contact the work. The bushing then helps support the tool through the machining process. Bushings are commonly used for drilling and reaming applications. They are not used for tapping operations, or operations like broaching or face milling, which do not manufacture holes.

The interaction of improperly matched tools and bushings is often a cause of premature tool failure. In the case of an over-sized bushing the tool is not adequately supported and produces poor quality parts. The tool may also fail prematurely under these conditions. In the case of an under-sized bushing the tool breaks immediately as the station attempts to force the tool through the aperture.

Tooling

For the purposes of this discussion, tooling is defined as the portion of the transfer line which comes in contact with the work-piece and shapes or removes material to alter the geometric form of the workpiece. This narrow definition excludes items such as fixturing, or gauging apparatus, which is often included in broader definitions. This definition was adopted because it is these items (drills, mills, reamers, boring bars, etc.) which we wanted to better manage as part of this project. Nonetheless, the principals laid out here for the management of tooling can be applied to items contained within broader definitions of the term 'tooling'.

Figure 2-4 illustrates a typical automotive tool assembly. It consists of the actual tool, in this case a drill, and a tool holder, which is used to interlock the tool and machine spindle. The tool holder itself consists of several pieces, which are required to hold the tool accurately and securely. Because the rate at which tool holder components are replaced is much less than the rate at which the actual tools are consumed, the tool holder assembly will be considered as a single item.

Figure 2-4: Typical automotive tool assembly. The assembly consists of the tool itself, as well as a specialized holder designed to make it easy to mate tools to spindles while providing a high degree of alignment. [T.M. Smith Tool International]

In job shops "standard" tools are generally used. These tools are sized to generate holes or features corresponding to a well established standard. For example, standard drills are produced in 0.25" (1/4") and 0.375" (3/8") diameters, but not 0.3678". Also, a standard tool is generally dedicated to creating a single geometric feature, such as a hole with one diameter. In mass production facilities the tooling, like the machine tools, is much more specialized. Custom tools are used to create several geometric features with a single operation, and the sizes of the tools are often non-standard. For example, a single tool used in engine manufacturing might drill a hole with two distinct diameters, and ream and chamfer the larger hole as well.

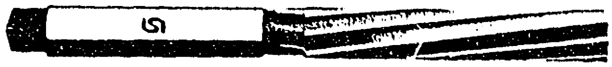
Figure 2-5 illustrates typical tooling found in a cylinder head machining department. Each type of tool is briefly described below.

Drill- Drills are typically made out of high speed steel or carbide. They are used to create holes in the workpiece at high metal removal rates, but with only limited accuracy. These tools are typically regrindable. As the cutting edge wears down the tool can be sharpened to create a new point. The number of times the drill can be reground depends upon the tolerance of the drill, the amount of back taper on the drill, and the amount of material removed during regrinding.

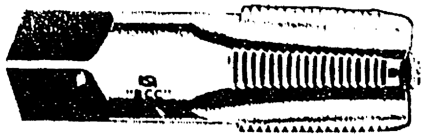
While single-step drills are the most common in job shops, step drills are often used in mass production. These drills, which are manufactured with two or more diameters are used to create compound holes.

Reamer- Reamers are used to improve the accuracy of holes created using a drill. These tools use multiple flutes to remove a small amount of material while maintaining a high degree of concentricity. Reamers are typically regrindable, and are manufactured of high speed steel or carbide. As is the case with most tools, insert-based reamers are available, although they are used infrequently. Insert tooling uses disposable cutting edges in a reusable cutter body, rather than forming the cutting edge and tool body from a single piece of material. Insert tooling, while more expensive, allows a wider range of materials and cutting edge geometries to be employed by decoupling the cutting and structural support functions required of a tool.

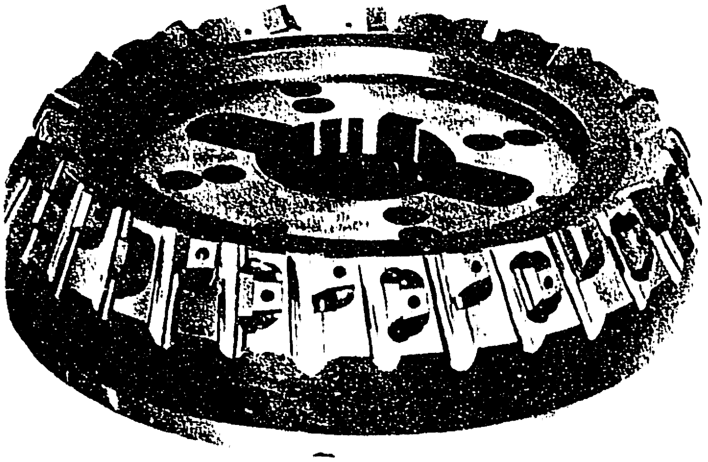
Twist Drill



Reamer



Tap



Face Mill

Figure 2-5; Tool types typically used in the manufacture of cylinder heads. The tools presented here represent standard tools. Specialty tools, with more complex geometries combine multiple cutting edges in a single unit. [McMullen Tool Supply Company]

Face Mill- Face mills are used to generate surfaces on the workpiece. Typically, face mills are used to create flat surfaces, such as on the bottom (joint face) and sides of an engine head. Face mills are increasingly designed to use inserts, thereby increasing tool life and reducing production costs. Inserts for milling applications are generally manufactured from carbide or diamond-based compounds.

Tap- Taps are used to create threaded holes, which during assembly will accept bolts and screws. Taps are generally not regrindable, and so when they wear out they are scrapped. In order to use a tap a suitable hole must first be created using a drill.

Form Tool- Form tools are often used to cut complex geometries, such as the valve seat pockets and throats on an engine head. These tools are often manufactured from solid carbide, or using a carbide tipped brazed construction, making them very expensive. Their unique geometries, and the incorporation of several geometric features on a single tool, also contributes to their expense. While most form tools are regrindable, insert-based form tools are becoming popular for many applications.

2.2 The Role of Tooling in Mass Production Metal Cutting

Mechanically speaking, tooling acts as the interface between the machine tool and the workpiece, removing material to create desired geometries and surface characteristics. This is tooling's primary role. If a tool does not adequately perform this function, as measured by part quality and production cost, the tooling is considered to have failed at its task. As a result, the design of tooling, and the manner in which tooling is purchased by Chrysler from vendors, places a high value upon the ability of tooling to perform this basic mechanical function.

To recognize only the mechanical function of tooling would be an oversimplification of the role that tooling plays within TEP. In addition to its basic mechanical function, tooling plays at least four critical roles in plant operations.

1. Tooling as Safety Valve

As previously described, tooling acts as the interface between the machine tool and the workpiece. It is also the weakest part of the mechanical structural loop created by the machine tool, tool, fixturing and workpiece. As a result, malfunctions of any of the elements in this loop generally lead to tool failure. Problems include, but are not limited to, tooling related errors like misalignment, improper size, and worn cutting edges.

Problems such as misaligned machine tools, inadequate coolant, overly hard workpieces, damaged spindle bearings, and improper machine feed and speed settings are all likely to cause tool failure before significant damage is caused to the machine tool or fixturing.

2. Tooling as "Quick-Fix"

A second role of tooling, related to the first, but yet distinct, is that of a quick-fix. Often, when operational difficulties are encountered on the transfer line the plant does not want to shut down the line for the necessary repairs. Particularly strong resistance to shutting down the line is met when the buffer of parts between the line in question and successive departments is small. In order to prevent down-stream manufacturing operations from being starved for parts, tooling is fed into the line to compensate for the problem. For example, if a spindle bearing deteriorates to the point where excessive vibration causes tool failure, the production manager may choose to keep the line running through one or more shifts (assuming good parts can be produced) until there is enough time to replace the spindle without threatening downstream production. To do this a large amount of tooling will have to be consumed. Thus, tooling is often used as a stop gap measure to enable production. This function of tooling is made possible by the weak-link status of the tool in the machine-tool structural loop.

While the use of tooling for this purpose has a legitimate place in the plant, it is often abused. Necessary repairs are often delayed far into the future. Or, repairs are not even considered until the plant runs out of the tools needed for the malfunctioning operation. Use of tooling in this manner boosts total consumption, leads to larger tool inventories and results in poor quality parts and additional scrap.

3. Tooling as System Decoupler

The operation of a mass production metal working facility requires that a large and varied set of skills be brought to bear upon the basic manufacturing process. At TEP these skills are generally divided into functional departments. In addition to the machining departments, support departments provide the material and knowledge needed to make production possible. The common thread between many of these departments is the tooling used on the transfer line. Tools are used in machining departments, stored and distributed by the Tool Crib, and reground by Cutter Grind. Each of these departments builds up its own inventories of tooling to insulate its operations from the activities of the other departments. The functions of each of these departments are described in greater depth in Chapter Three.

The Tool Crib builds up inventories of sharp tools to insure that it has enough tools to supply the machining department's projected needs. It uses a computerized inventory management system to monitor consumption and plan purchases. The Tool Crib acts to insure itself against any variation in the "production" of reground tools by Cutter Grind, and variations in tool consumption in the machining departments. Cutter Grind and the Tool Crib also build up inventories of dull tools to enable large batch processing of tools by Cutter Grind. This method of processing is preferred because it requires fewer set-ups, and is therefore less labor intensive, than the processing of smaller batches of tools which more closely track machining department consumption. Finally, the machining department builds up its own inventories of sharp tools to insulate its operations from variations in Tool Store and Cutter Grind activities.

All of these inventories serve to isolate the functions of each tool-handling department from the other areas. As a result total tool inventories are high. In addition to the high costs of carrying this inventory, the tool inventories serve to reinforce the inefficiencies of each of these departments by reducing pressure for improved performance. This is the classic "water over the rocks" effect commonly associated with high levels of finished goods, or WIP, inventory.

4. Tooling as "Scape Goat"

When bad parts are manufactured in the transfer line the first item to come under suspicion is the tooling. The immediate response of production managers to the manufacture of scrap parts is to replace the related tooling. Often this creates a temporary improvement in the quality of machined parts. But, many times the use of new tools only masks more fundamental machine or material conditions. When the second and third set of tools are replaced, managers become convinced that indeed the tooling was the problem, and that new tools must be ground by cutter grind, or brought in by the vendor. Often the "bad parts-replace tools-bad parts-replace tools...." cycle does not lead managers to question elements beyond the tooling itself. This occurs because tooling is often the cause of poor part quality, and because the destruction of tooling reinforces the belief that the tooling itself is often to blame. Furthermore, production managers have more control over tooling than they do the personnel required to diagnose and repair machine tools and related systems. Finally, production managers, maintenance personnel, and engineers usually operate in a "fire fighting" mode and so exploration of a problem beyond its more obvious elements (e.g. - broken tools and bad parts) does not occur until the department is in dire straits.

2.3 Human Resources in the Mass Production Environment

Chrysler employees at TEP are divided into two broad categories: hourly and salaried workers. Hourly workers are members of the United Automobile Workers (UAW) and perform the production and support functions associated with engine manufacture. Hourly workers staff production machinery, move and catalog material, and maintain the facility. Salaried employees are involved primarily with planning, control, and supervisory tasks within the plant. Most tasks within the plant are designed and dictated by salaried employees and performed by hourly workers. A basic organization chart for TEP is shown in Figure 2-6.

The workforce at Trenton is fairly old, averaging about 46 years old, and almost 26 years of service to the Corporation. The workforce is so advanced in age because of intense manpower reductions, or tasks, in place since 1979.[1] Each year TEP management is given a task to reduce manpower by so much. Typically these reductions are achieved by offering incentives for workers to retire, but layoffs are sometimes required as well. As a result of these tasks few new workers are hired into the plant, and workers with low seniority are laid-off. This leaves the plant with older workers who have high levels of seniority.

Relations between hourly workers and salaried workers, or management, range from cordial to hostile. Both groups tend to lay the blame for problems within plant at the other's door step. Coordination between the two groups to solve plant-wide problems, and develop new ways of doing things is generally poor. In response to this deficiency, programs such as the Product Quality Improvement (PQI) have been developed to foster greater interaction and cooperation between management and hourly workers. While the success of these efforts has been limited to small pockets within the facility, PQI teams have been forming at a higher pace in the plant's new machining departments.

Beyond the classifications of hourly and salaried workers, hourly workers are further divided into production and skilled trades units. Production workers are specifically responsible for manning production machinery, maintaining part quality, and handling raw

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[1] Interview with Steve Lankford, Chrysler Corporation, Trenton, Michigan, 10 May 1993.

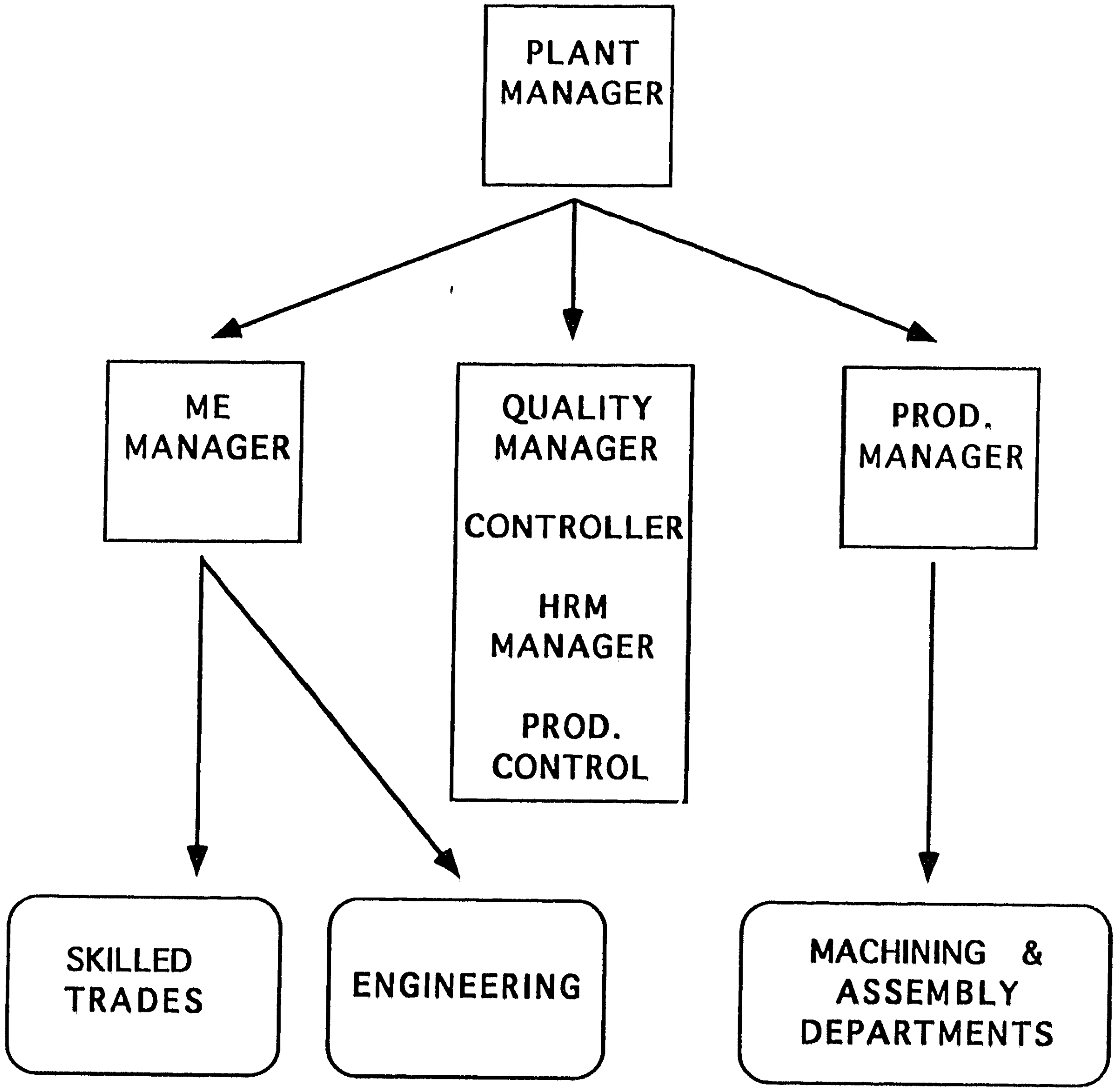


Figure 2-6: Simplified organization chart for TEP prior to January, 1993. Note the separation of support functions, such as engineering and the skilled trades departments, from production.

materials, WIP and finished goods. Skilled Trades workers are more specialized than the production workers, and are generally apprenticed into a specific role such as pipe-fitter, electrician, tin-smith, tool maker, millwright, or machine repairman. These workers earn higher pay and carry out construction and maintenance tasks for machinery and facilities. The cutter grind department, for example, is manned by members of the skilled trades, while the tool crib, which is essentially a material handling function, is staffed by production-classified workers.

The distinctions between skilled trades workers, by virtue of their specialized training, are great, and there are many fewer classifications among production workers. This is partly a result of the Modern Operating Agreement (MOA), a type of Chrysler-UAW contract which emphasizes cooperation and team building, as well as flexibility, among production workers, and which does not apply to the skilled trades. Production workers in a machining department, like the 3.5L head line, are principally machine operators. One or more workers are assigned to each operation within the transfer line, and they are responsible for maintaining production and part quality within that operation. In practice this job consists of loading and unloading parts from the operation, gauging parts and tracking part quality, and informing the appropriate parties when the machinery is not operating properly.

In addition to the machine operators, production workers called job-setters play a key role in keeping the production line running. Job setters are responsible for adjusting tools and installing them in the production machinery to replace worn or broken tooling. While in some departments this task is also performed by the operators, typically it is a distinct function. In addition to replacing tooling in the line, the job setter maintains the department's tool inventories in a local fenced in area, or crib. The job setter and operator are critical elements with regard to tool management because they are the first to identify tool related problems and because they regulate and monitor the condition of tooling in the production departments.

While product and industrial engineers within TEP are salaried workers, tool and plant engineers are members of UAW Local 412. Most of the engineers in Local 412 have been promoted from the factory floor, and were originally skilled trades members of Local 372. These engineers have limited formal education, and their skills are derived from years of experience on the factory floor. The relationships between tool and plant engineers, and plant management is a fairly confrontational relationship built upon a complex set of work rules.

The elements of human resources, machinery, and tooling interact to define the production environment at TEP. These interactions are in-turn defined by many influences, including the cultural biases of Chrysler management (within and outside of TEP) and the UAW in the areas of technology, automation, and labor relations. The interaction between Chrysler management and the UAW, as dictated by these biases, and external pressures from customers, suppliers, competitors, and governments also shape the production environment at TEP. An understanding of the inputs that dictate the characteristics of the TEP production system is essential when working to improve that system. During the development of the tool management system described, our successes and failures were closely linked to our understanding of the aforementioned inputs. These issues will be discussed at greater length in Chapter 5, when the pilot implementation is detailed.

3.0 Pre-Pilot Tool Management at Trenton Engine Plant

In this chapter I will describe the current methods used to mange tooling at TEP. I will begin with a general overview of the systems in place to distribute, store, and manufacture tooling. The mechanism for purchasing tools, which was beyond the scope of this project, but which eventually must be included in any comprehensive tool management system, is not detailed in this thesis. This overview is followed by a discussion of the availability of tooling-related information, and a look at practices within TEP for evaluating tooling performance. Finally, a set of five performance measures, designed to evaluate tool management operations, will be presented. These measures will be used to evaluate tooling performance within TEP's three head lines.

3.1 Storage and Distribution of Tooling

The current system for tool storage and distribution is shown in Figure 3-1. This figure illustrates the flow of both material and information related to the use of tooling at TEP.

Receiving & Wholesale Tool Crib

Ideally, new tools enter the plant through the highly regulated tool crib area. Tools are "received" and then sent to the gauge management area, where inspectors spot-check 10% of the incoming order to insure that it is within print specifications. Shipments containing tools which do not pass inspection are returned to the vendor. Accepted tool shipments, which range in size from one tool to several hundred, are then stored in a storage system called the high rise, within the wholesale crib. This area is secured from the rest of the plant by fencing and locked entrances. Tools which are specifically intended for use in one machining department are sorted in the high rise by tool number (T#). The tool number designates the particular department in which the tool will be used, and, in conjunction with a process print, identifies the station on which the tool will be used. Standard tools are not issued T#s. Because these tools will be used in many machining departments they are stored together. Thus, tools are stored in the high rise as a function of tool geometry. There is a separate storage location for each special tool, as represented by a T#, and each type of standard tool, which is identified using a Chrysler code number.

Retail Tool Crib

The retail crib links the wholesale crib, cutter grind department, and machining departments together. Tools which have been used at least once in the machining

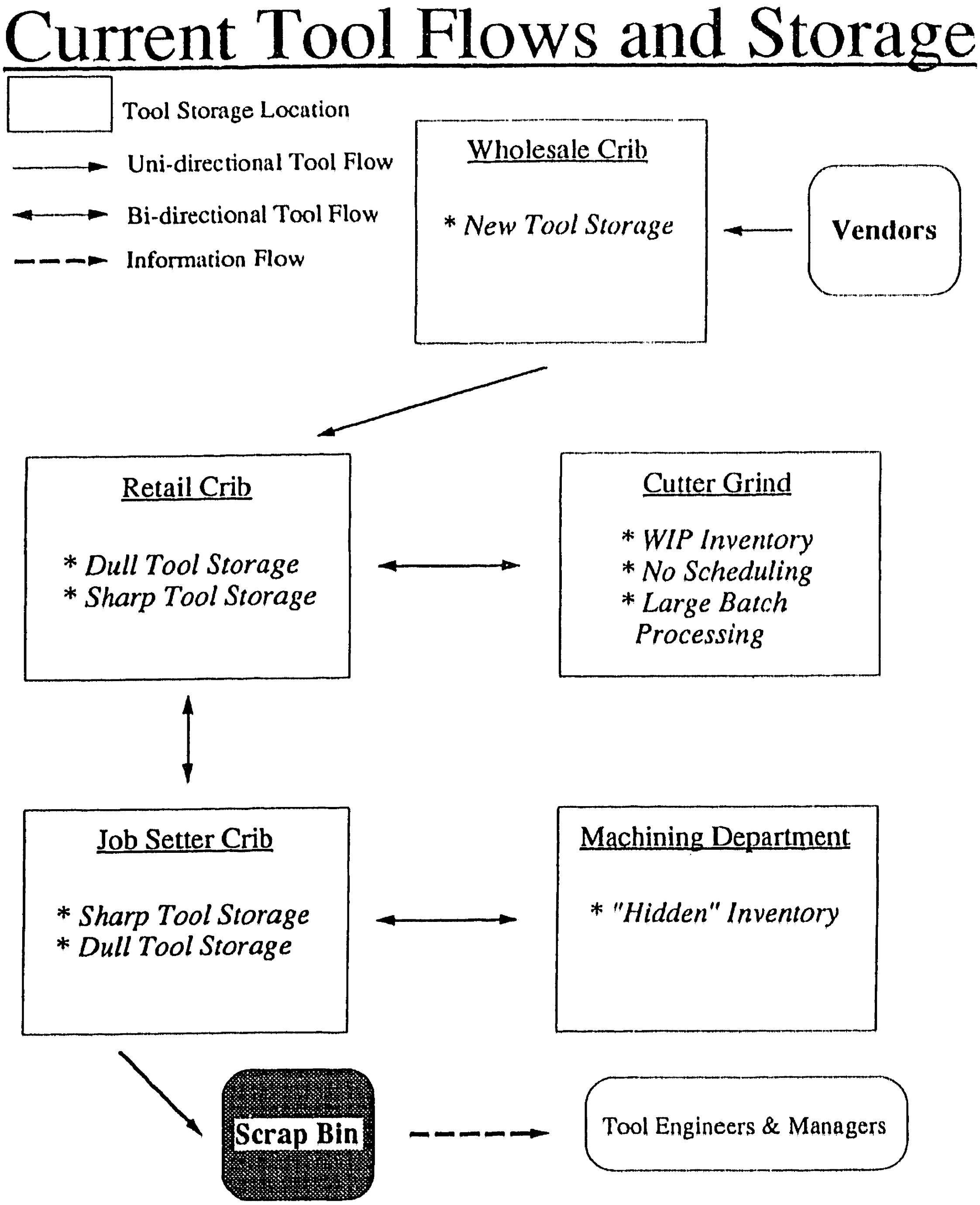


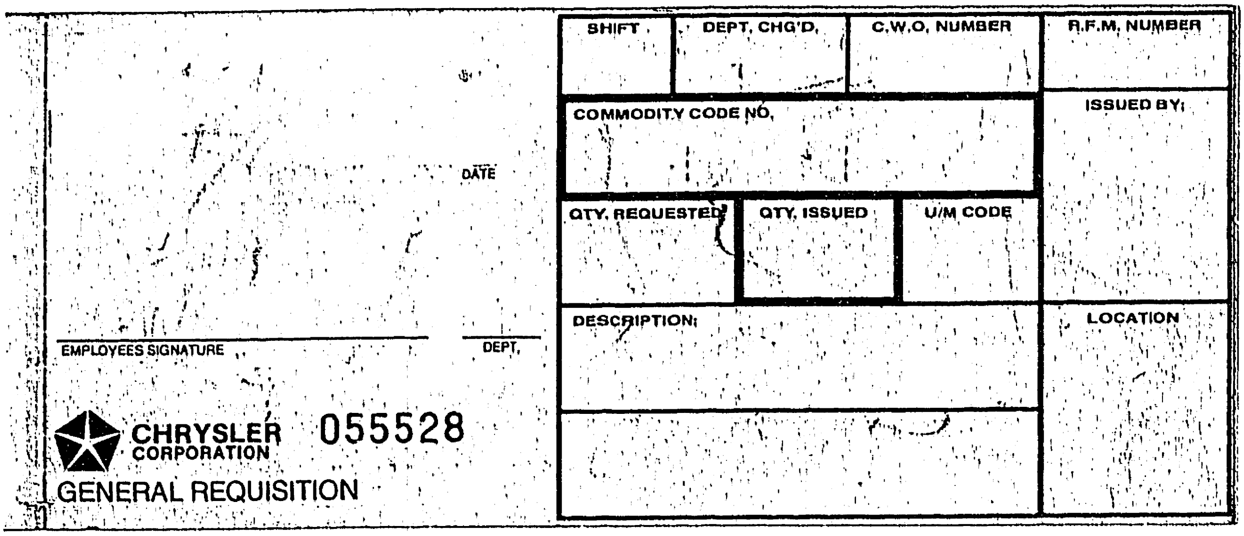
Figure-3-1: This figure outlines the flow of both information and tooling within traditional tool management systems. Note that information is only generated when a tool is scrapped. It is also significant that there are five inventory locations, and a total of seven different piles of tooling (the sharp and dull tools are effectively independent inventories).

department are stored here. Sharp tools that have not yet been used reside in the wholesale crib. Tools are arranged by T# or Chrysler code number, and for each tool there are two storage locations - one for sharp tools and another for dull tools. The tools are piled in drawers without being coated or otherwise protected. As a result, contact between tools, and between tools and the metal drawers they are stored in, can damage the cutting edges of tools. This is more of a problem for the sharp tools stored in the retail crib than it is for dull tools.

Tools enter and exit the retail crib, which like the wholesale crib is a secured area, through three paths. First, worn tools are brought by machining department personnel to the window where they can be exchanged for sharp tools on a one for one basis. Each exchange is accompanied by a general requisition which details the department from which the tools are coming, and their T# or Chrysler code number. The retail crib attendant takes each worn tool and puts it in the appropriate "dull" drawer. Then the crib attendant takes a reground tool from the "sharp" drawer and gives it to the production worker. Figure 3-2 provides an example of a general requisition.

Tools are also transferred between the retail crib and the cutter grind department. When "enough" dull tools accumulate in a particular drawer they are sent through a window to cutter grind, which is adjacent to the retail crib area, for processing. Eventually these dull tools will be processed and returned to the retail crib, where they will be stored as sharp tools. Tools are not transferred to cutter grind in a systematic manner. Crib workers judge, based on the number of sharp and dull tools on-hand, which tools should be sent to cutter grind. Often, batches of more than twenty dull tools accumulate before the tools are transferred to the cutter grind department. For many machining operations this represents several weeks worth of tooling. Figure 3-3 illustrates a typical distribution of batch sizes for dull tools sent to cutter grind.

There are occasions when tools are transferred from the retail crib to cutter grind in small batches. This occurs when a machining department consumes a large number of tools in a very short period of time. In this case only a small group of tools is sent to cutter grind because most of the particular T# or code number tools in question have been broken or damaged. This situation arises when tools are being consumed in order to alleviate a machining or stock condition.



EMPLOYEES SIGNATURE

DATE

DEPT.

CHRYSLER
CORPORATION

055528

GENERAL REQUISITION

SHIFT	DEPT. CHG'D.	C.W.O. NUMBER	R.F.M. NUMBER
COMMODITY CODE NO.			ISSUED BY:
QTY. REQUESTED	QTY. ISSUED	U/M CODE	
DESCRIPTION:			LOCATION

Figure 3-2: General Requisition for the acquisition of tools, and other material from the wholesale or retail crib. This form allows any employee to obtain material from the cribs. The requisition is then used to create an entry into TEP's computer system, NPICS.

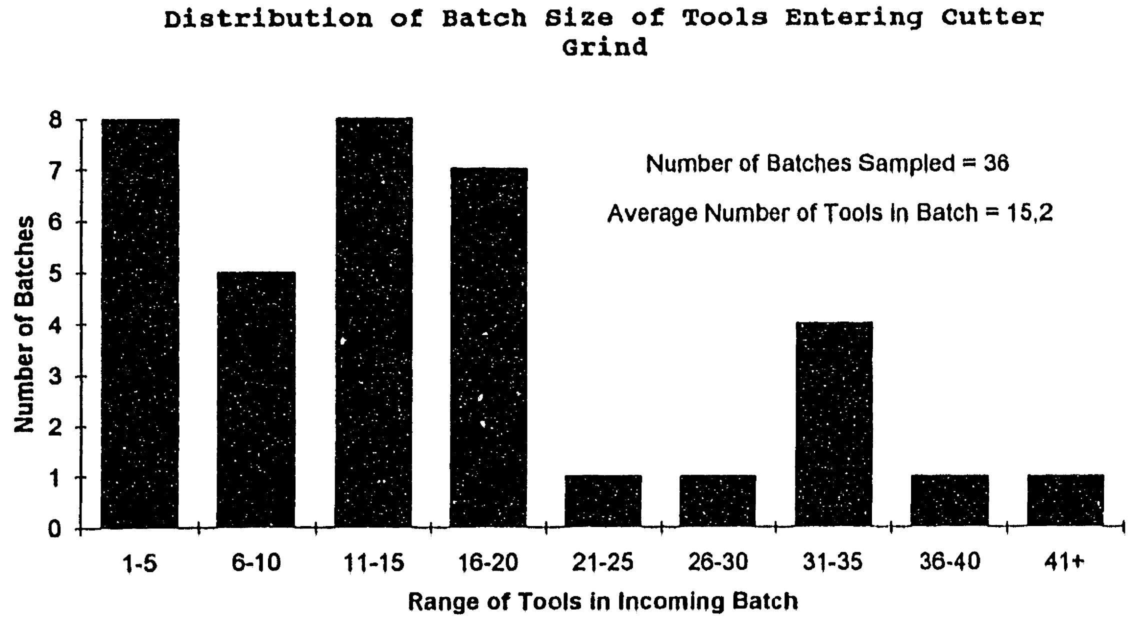


Figure 3-3: Batch sizes for tooling delivered to cutter grind department. Tools are transferred to cutter grind from the retail crib in batches by tool number. The above distribution is from one day, October 5, 1992. Note that while most batches contain less than twenty tools, almost 25% of all incoming batches contain twenty or more tools.

Finally, tools enter the retail crib from the wholesale crib. This occurs when the machining departments return broken, or over-worn, tools that can't be reground, to the retail crib. In this case the damaged tools are collected by the retail crib and scrapped. A replacement tool is issued to the machining department from the sharp drawer and that tool is in turn replaced with a tool from the wholesale crib.

The same group of personnel man the wholesale and retail cribs, even though the inventories in each area are kept distinct from one another. Both areas are staffed on all three shifts. The first shift is the lead shift, and has the highest staffing levels. This is a result of the large number of incoming deliveries during this time, and because the majority of tool transactions between the machining departments, cutter grind, and retail crib occur during this period.

Cutter Grind Department

The cutter grind department is responsible for reconditioning worn tooling so that it can be used in TEP's machining departments. After machining a given number of pieces, the cutting edges of a tool wear away. When this happens the tool no longer cuts metal, and instead rubs, or burnishes, the workpiece. This is an inefficient way to remove material and leads to poor surface finishes and improper workpiece dimensions. The regrinding process removes a small portion of the tool tip and creates a new cutting edge. Regrindable tools can be reground upwards of ten times, depending upon the condition of the tool prior to regrinding, the tolerances required of the tool, and the skill and conscientiousness of the cutter grinder. It can take anywhere from one to ten minutes to regrind a single tool, excluding set-up time, depending upon the number of cutting edges on the tool. Set-up times range from between five to fifteen minutes and are performed prior to grinding a batch of tools.

The cutter grind department is the critical element of any tool management system. The department regulates the flow of tooling through the tool management system (it is the bottleneck) and dictates tool inventories throughout the system. The quality of tooling, and therefore the quality of the workpieces made, is also determined in this department. Just as the design of a new product dictates many of the characteristics that the product will take on in downstream processes (e.g. - cost, quality, and manufacturability) the cutter grind department dictates the performance of a tool management system, and to a large extent the production environment supported by the tooling. In short, a well run cutter grind department is a prerequisite for efficient manufacture within a mass production metal working facility.

Trenton's cutter grind department is staffed by about ten personnel on first shift and seven additional cutter grinders on the second and third shifts. The area is poorly lit, dirty, and noisy due to the presence of two large dust collectors in the area. Collectors like these usually run silently, but those in cutter grind have not been properly maintained. The majority of productive capacity in the department resides in three machines, two computer numerically controlled (CNC) tool grinders, and a computer controlled broach grinder. These machines and their operators process about 50% of the total throughput of this department.[2] This is particularly intriguing when it is recognized that these machines are only operated consistently on the first shift. The remainder of the department's machinery is outdated manual machinery which was designed for grinding tools with fairly simple geometries. Many of the complex-geometry tools in use at TEP today can not be ground properly on this equipment. As a result, the CNC tool grinders and their operators are relied upon to process an increasing proportion of the plant's tooling. These man-machine teams have effectively become the bottleneck for the department, and the entire plant, regarding the availability of tooling.

While the demands placed upon the CNC equipment and its operators have increased, the work load placed upon other workers in the department has declined. This is in-part because of a tradition of specialization within the department. There is a "saw-man", a "drill-man", a "broach-man" and so on. These informal classifications, which grew out of the department's history and culture, rather than any corporate or UAW mandate, were established decades ago. As the mix of tooling used at the plant has changed over the years, the work load within the department has changed as well. But, the classifications, and the skills possessed by the department's workers have not changed with the times. As a result there is a broad inequity in the work load carried by workers in cutter grind. Some workers are busy for a full eight hours, plus overtime, while others perform less than two hours of work per day.

Work within the department is largely self-directed. Large numbers of worn tools enter the department from the retail crib and are indiscriminately placed on tables throughout the department. These tools are effectively work-in-process inventory, and will often sit

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[2] Interview with Bill Nichols, Chrysler Corporation, Trenton, Michigan, 8 May 1993.

for weeks before being ground. There is no relationship between where tools are placed and the processing steps that will be required to regrind them. Thus, there is no well defined process flow within the department. It is largely dependent upon each worker's preferences.

The result of this ill-defined work flow is that WIP in cutter grind swells and diminishes in long-period waves. Over the period of a month or so the number of tools waiting to be reground will grow until they are piled up on all available counter space and the floors as well. Tool shortages will then begin to occur in the plant with greater frequency, leading to a period of frenzied activity on all three cutter grind shifts, as workers try to get managers, who are now pressuring the department for output, off their backs. WIP levels will quickly recede over a week or two and then begin to build back up until another series of crises hits.

Workers generally choose the tools they will grind based upon the ease with which they can be processed. This corresponds to those tools which require a simple set-up, and for which a large number of items require processing. In this way a single set-up can be prepared and then a large number of tools can be ground, in an almost robotic fashion. Tools are not ground in relation to the order in which they were delivered to the department by the retail crib (a rough approximation of the demand for those tools), nor are there any records kept by cutter grind detailing when tools entered or exited the cutter grind department.

This selection criterion is often over-ridden by emergency jobs. Emergency jobs occur when a machining department is "down" because it has run out of good sharp tools. This occurs when the department consumes a high number of tools, when tools previously ground by cutter grind are of poor quality, or as a result of a build-up of WIP in the cutter grind department.

In order to grind the tooling, a print detailing the tool's dimensions must be consulted. The print dictates the geometry required on that tool (e.g. - point geometry, secondary angles, etc.) and must be consulted to ensure that after being reground the tool is not undersize. This occurs when a tool has been reground too many times, and the point has been moved back so far along the back-taper that it becomes too small to use in production. Checks must also be performed to insure that the overall length of the reground tool is acceptable.

When tools are ground on the CNC grinders these prints are used to create part programs which control the motions of the grinder. The CNC machinery forces its operators to be fairly diligent in ensuring that the proper tool geometry is created during the regrind process. If the wrong geometry is entered into the CNC serious damage to the CNC machinery may result. When tools are ground manually there is a tendency for cutter grinders to "touch-up" the point of the drill without looking at the print. This activity is reinforced by the fact that many of the necessary prints are not on file in the department, and tool changes are often not updated on the prints in cutter grind. Furthermore, for standard twist drills and other simple tool geometries, well established standards dictate the point geometry. Nonetheless, many poor quality tools are created by the department because the tool prints are not consulted.

Once tools are ground they are supposed to be inspected before they are sent back to the retail crib for distribution to the machining departments. Each worker is responsible for inspecting his own work prior to returning the tools to the crib. Unfortunately, standardized inspection procedures are non-existent in the department. While no firm estimates are available, as many as 10% of the tools ground in the department are improperly processed and passed on to the retail crib.[3] This percentage is much higher for tools ground manually than it is for those ground by the CNC machines. Interestingly, this trend has made the use of additional CNC equipment in cutter grind more attractive to plant management, despite the current under-utilization of man-power and capital in the department. Because there are no records indicating who ground which tools, and because reground tools may not find their way into a machining department for several weeks (as a result of high tool inventories) it is difficult to establish accountability regarding tool quality.

Inspection procedures are also thwarted by emergency job processing. When a lack of tools limits production in the plant, cutter grind is forced to process the needed tools in a very short time span. Generally, tools will be removed from cutter grind before any inspection can be performed. The machines in the production department are then used to "inspect" the tools by running parts, often creating scrap and additional down-time.

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[3] Ibid.

Job-Setter Crib

Each machining department within the plant has its own secure area for the storage and preparation of tools. These areas are fenced in and located adjacent to the transfer lines of the department. Each crib is staffed by one or more job setters, who are production workers trained to set-up tools for use in the transfer line. Set-up procedures are required to take the tools obtained from the retail crib and mate them with the appropriate holders. In the present tool management system these holders are not handled by either the retail crib or cutter grind department.

In addition to mating each tool with the proper holder the tool height must be set. The tool height is an important parameter because it determines the geometry of the cut made by each tool. A tool that is set too short will create parts that need to be repaired. One that is set too long will often create unrecoverable scrap. The tool "setting" is done using a height gauge, which can be either mechanical or electro-optical in nature.

In addition to setting tools, job setters replace tools in the transfer lines as they break or wear. In a few departments they also replace tools in the machines on a pre-set schedule. To enable the replacement of tools on short notice, the job setters store at least one of each type of tool in their cribs. In practice a much larger number of each tool type is stored. The job setters maintain extensive inventories of sharp tools to insulate themselves from the retail crib and cutter grind departments. Often these inventories are "off-the-books" in that they are not recognized by any of the tracking systems used within the plant. These inventories begin to grow when the department first comes on-line. Tools for the department are initially purchased with the line and are located in the job-setter crib to enable rapid response to the many problems a new transfer line experiences. Over time these inventories expand through stockpiling, which is interpreted by the retail crib as consumption, and through the acquisition of tools which have not been handled by the tool cribs. These effects will be discussed in greater detail below.

In addition to storing sharp tooling, job setters accumulate quantities of dull tooling that have been removed from the transfer line. These tools are stored, rather than returned to the retail crib right away, to minimize the number of trips the job-setters must make to the retail crib. For some departments the retail crib is a ten minute walk away. An unscientific survey of job setter cribs indicates that local inventories of dull tools are proportional to the distance between the job-setter crib and the retail crib.

Machining Department

In addition to the tools stored within the somewhat secure job setter crib, tools are stored locally at each operation and/or station of the transfer line. Holders with properly set tools are kept in tool boards to make it easier for job setters to replace tools, and to allow machine operators to change tools as well. By putting tools in close proximity to the transfer line the amount of down-time during a tool change can be minimized, and tools can be changed by the operator without requiring the involvement of other personnel. Unfortunately, this also encourages the consumption of tooling to cover up for machine or other conditions, and can increase the amount of time before a supervisor or engineer learns that there is a significant problem with the machining operation.

When a transfer line is designed and installed, each tool used in the line is assigned a tool life. This value, which can range from 1,000 to 100,000+ depending upon the tool and workpiece, indicates the number of parts that can be processed with the tool before it requires regrinding, or in the case of insert tools, replacement. In practice, tools are run in the transfer line until the periodic inspection of parts reveals degradation of feature geometry or surface finish. This can be a result of normal tool wear, tool breakage, or machine and stock related problems. The operation in question is stopped, the tool is removed and a sharp tool takes its place. No records are kept detailing the number of pieces made by the tool. Some operators have improved this process by replacing groups of tools at the beginning of their shift. This allows several tools to be changed at once, rather than having to replace tools piecemeal as they wear down. By the same token, many tools which should be changed are left in the machinery until the end of the shift when they can be changed more easily, or when a different operator will become responsible for them. Finally, many tools aren't changed until they have become excessively worn, or are producing bad parts, because workpieces are inspected infrequently.

Underground Tool Economy

The aforementioned description, as represented by Figure 3-1, addresses the storage and flow of tooling as it is intended to occur within the plant. But, a description of the tool management system currently in place would be incomplete without accounting for the unofficial routes through which tooling moves in the plant, and the presence of inventories not sanctioned by the TEP staff.

Figure 3-4 is a reproduction of Figure 3-1 with additional material flows and storage locations added. These flows and storage locations have become a part of the system at Trenton by necessity rather than design. Failings in the formal system led department managers, machine operators, cutter grinders, and others to create an additional framework to allow them to perform their jobs and support production.

All of the additional flows and tool storage locations are aimed at providing the machining department with an adequate supply of tooling, and insulating the department against supply shocks caused by the retail and wholesale cribs, or cutter grind. Because machining department managers are evaluated based upon their ability to produce machined parts they often take whatever steps are necessary to achieve this goal, whether or not they are, as a matter of record, accepted. In fact, the prevalence of these "underground" activities indicates that they are accepted as necessary steps to maintain production. They have become an ingrained part of the TEP culture.

Machining departments operate outside the formal system when their ability to meet production quotas is threatened by a lack of tooling. When this occurs tools are taken from inspection before they have been checked, tools that failed inspection are removed from shipping and receiving, vendors are asked to bring shipments directly to the machining department without properly processing them with the tool crib, and "test" tools are obtained from vendors. This last item is particularly unsettling because tool designs that have not been qualified for use on the line enter the production process, and over time become interspersed with quality tooling. This further increases uncertainty regarding the condition of tooling used in the machining department.

As previously mentioned, many of the tools in the machining departments are not recognized by the plant's accounting system as inventories. Instead, they have been counted as consumption. This occurs because each time a production worker obtains a new tool from the retail crib it is supposed to be replacing a tool which reached the end of its life. But, through the mechanisms mentioned above, a substantial amount of tooling accumulates in what we have termed "hidden inventories". These inventories are hidden in the sense that they are not recognized by plant control systems, even though they exist. These hidden inventories reside almost exclusively in the machining departments. They are found in job setter cribs, piled up in cabinets near the transfer lines, and in workers' tool boxes . Estimates place the total value of this hidden inventory for the head lines at a level equal to or in excess of the recognized inventories detailed

Underground Tool Flows

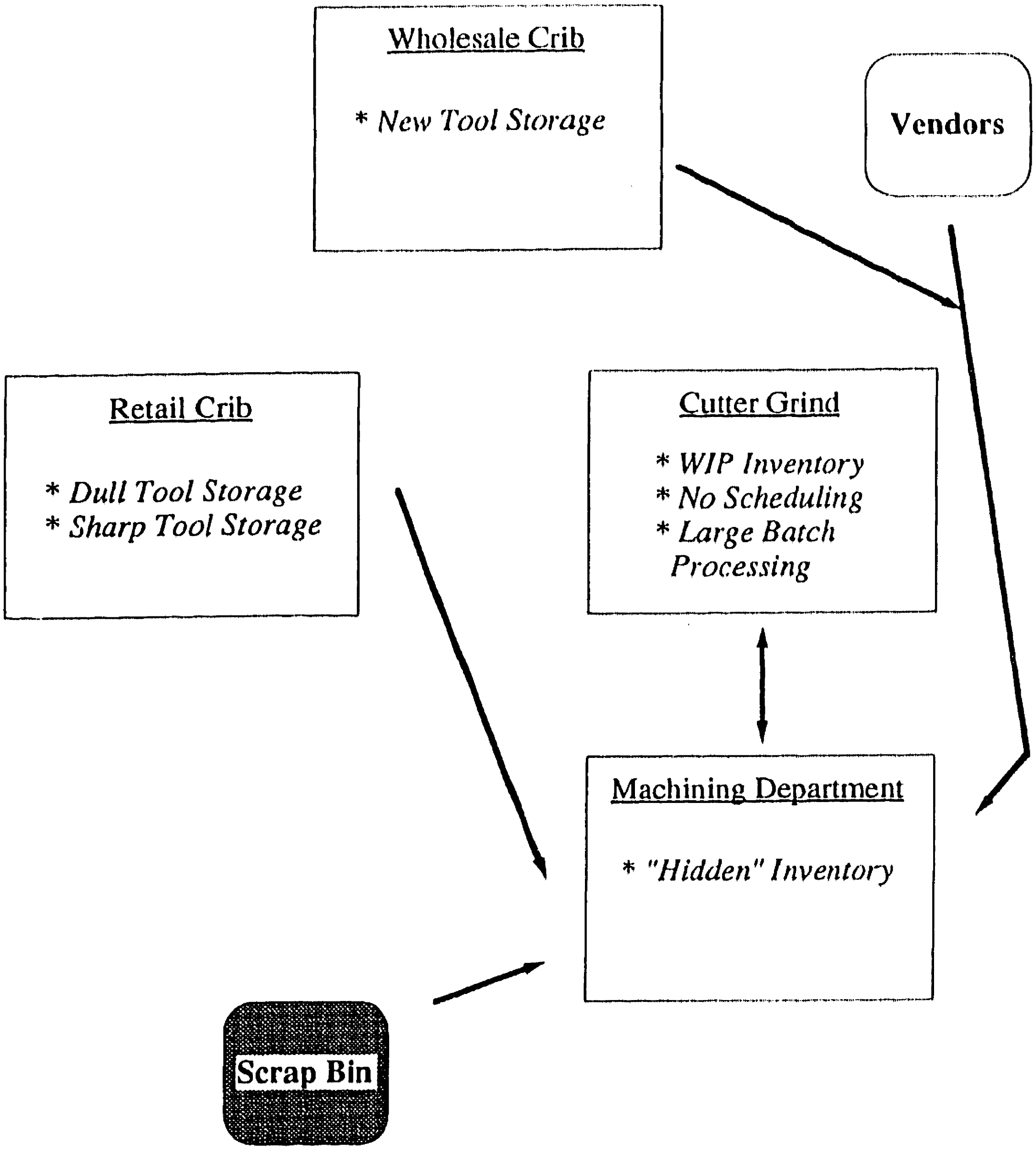

Figure 3-4: The above flows represent the paths used to bring tools to production departments outside of the tool management system presently in use at TEP. These tools include tools that have been classified as scrap, and tools that have not yet been inspected. When tools enter the production departments through these routes they can not be tracked by the plant's inventory control systems.

above and represented pictorially in Figure 3-1. Thus actual tool inventories in the plant may be *twice* those accounted for.

These inventories grow during crisis periods, when machines need to be run at "all costs" and tools are fed into the machines regardless of the rate at which they are broken. Eventually, when managers realize that consuming tooling didn't alleviate the crisis the root problem is addressed. Once the crisis has passed the tooling that was stockpiled at the transfer line is not removed, swelling inventories and contributing to the uncertainty surrounding the quality of tooling available to the department.

3.2 Tooling-related Information Systems

Having described the flow and storage of physical tooling we can now discuss the flow of information surrounding these activities. This is an important concern because the quality and timeliness of tool-related information determines the extent to which the flow, quality, and inventory of tools can be effectively managed.

Much of the information regarding tool consumption and inventories is embodied in the tools themselves. The exchange system used by machining departments to obtain replacement tools from the retail crib is one such example. The flow of tools through the plant is also monitored using two independent computer-based systems, NPICS and a retail crib transaction monitoring system. These systems are augmented by the use of numerous paper-based exchange tickets.

NPICS

NPICS (Non-Productive Inventory Control System), is a computer system that monitors tool inventories in the wholesale crib. In fact, the system monitors all incoming material, not just tools. For each tool number or Chrysler code number, the system contains a series of records including monthly consumption, wholesale tool inventories, recent shipments received and ordered, and the tool price. The system receives its information through manual entries, which are triggered both by the receipt of a tool shipment and the removal of tools from the wholesale crib. NPICS generates purchase orders for tools automatically by comparing a running average of monthly removals from the wholesale crib to the lead time required to receive the tools from the vendor. The amount of inventory on hand is also taken into consideration.

NPICS can only monitor the flow of tooling into and out of the wholesale crib. Its region of influence is limited primarily to purchasing personnel because the system is not widely used by area managers or tool engineers to monitor tool consumption in anything but the most gross sense. NPICS uses a specialized command set that predates the development of menu driven user-interfaces, and the information it provides is often inaccurate and out-of-date. The detailed information it does provide regarding tool flows is displayed in a manner that makes citing trends difficult. These characteristics greatly undermine the system's usefulness for scheduling tool purchases and for discovering areas of excessive tooling costs. Unfortunately, NPICS is the principal vehicle for managing tooling at TEP.

To illustrate the weaknesses of NPICS as a means of managing tooling, consider a representative T# tool for which a "hidden inventory" of 50 sharp tools is stockpiled in a machining department, and for which relatively low volumes are stored in the wholesale and retail cribs. Assume that this tool, which is used on only one spindle in the transfer line, can machine parts for ten days before requiring regrinding, and that each tool is capable of being reground ten times. The lead time to obtain these tools from a vendor is about three months. Ignoring retail crib inventories, the machining department could run its transfer line for 500 days (50 hidden inventory tools X 10 days) before any interaction between the department and retail crib regarding this T# tool would be required. And, the department could operate for up to 5000 days before any new tools would be needed from the wholesale crib to replace scrapped tools. Based on this usage pattern, many months would pass between each instance where a tool was required from the wholesale crib. As a result, monthly consumption of the tool, according to NPICS, would drop to near zero and NPICS would not order any replacements. And, after six months of zero consumption NPICS will drop the tool from its ordering system altogether. This is good for the case when all is going well in the machining department; money is saved because unneeded tools are not purchased.

But, consider a variation of this scenario. Assume that there is a problem with the machining operation in question so that instead of lasting ten days, tool life deteriorates to a level where tools last three days between regrinds, and tools occasionally break in the machine. Despite the breakage of tools, the machining department doesn't take its scrapped tools to the retail crib, which would in turn trigger the removal of tools from the wholesale crib and notification of NPICS. Because the machining department has fifty tools, operators, who do not have access to plant-wide inventory information, see no need to trade-in broken tools for new ones. As a result, NPICS is not aware that a change in the pattern of tool usage has occurred. In fact, because 50 tools existed in the department prior to the reduction in tool life, it is probable that no tools have been removed from the wholesale crib since tooling performance began to slip. So, even though a significant deterioration in tooling performance has occurred, no one relying on NPICS can take action to adjust inventories and/or address the fundamental problem causing the 70% reduction in tool life. Eventually, the machining department will consume its fifty tools, requiring that new tools be pulled from the wholesale crib. At this time a record will be posted on NPICS indicating that 50 tools have been consumed and that there was insufficient wholesale inventory to replace them. But, this piece of information is insufficient to determine that there is a problem in the machining department. Previous withdrawals of tooling from the wholesale crib were probably so far and few between that insufficient data exists to distinguish abnormal usage from optimal usage. This effect is presented graphically in Figure 3-5, which shows how current tool management practices act as an information filter by removing from view those events, like tool breakage, which occur on a fast time scale compared to the withdrawal of tools from the retail and wholesale cribs.

The extreme (but still common) case of NPICS inadequacy occurs when the machining operation in question has performed at optimum levels for several months and then suddenly collapses. This might occur due to workpiece material changes, spindle failure, or a machine collision. Under these conditions the entire "hidden inventory" of fifty tools could be broken within two or three days. When the machining department finally approaches the retail crib for replacement tools little can be done. Few tools are available and NPICS had not ordered any tools because of the low levels of wholesale crib consumption that it observed over past months. A batch of tools must now be ordered on a rush delivery at a premium price. And, in the meantime, the department is shut down while it waits for the tools to arrive. While this failure is not caused by NPICS, it illustrates the limits of NPICS' ability to manage tooling. It is basically an inventory monitoring system with very localized awareness. Because of this it is not useful as a means of structuring intervention into a tooling problem before it becomes a tooling crisis. Ideally, a tool management system should be able to prompt intervention into a tooling problem when the first or second tool is broken, not when the fiftieth, and last available tool breaks.

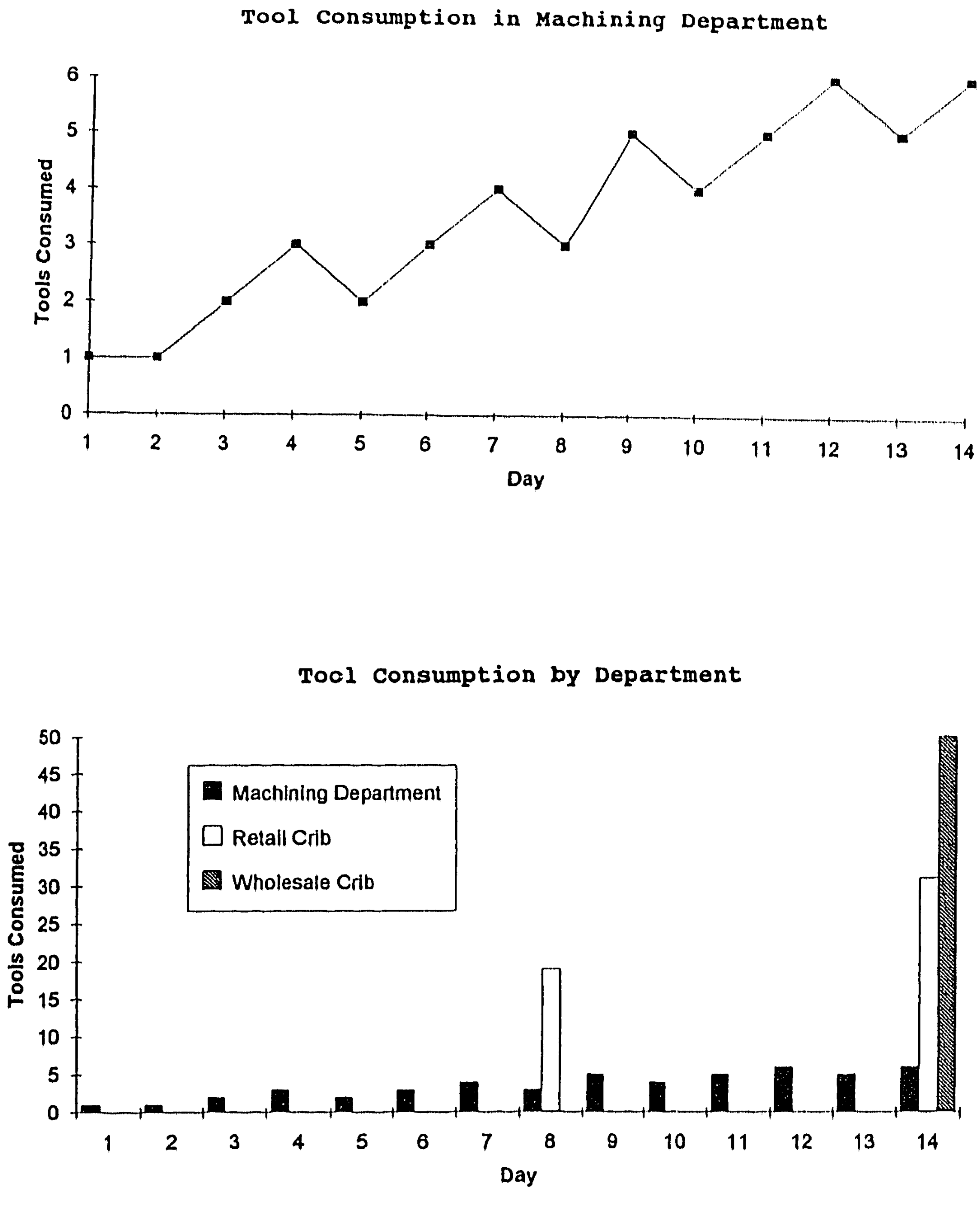

Figure 3-5: The graph at the top of the page shows that over a fourteen day period consumption of tools in the machining department is steadily increasing. But, as evidenced in the lower chart, this trend in increased tool usage in the department is hard to identify if only tool consumption at the retail or wholesale crib is monitored. For all three departments, total consumption over the 14 days is fifty tools. NPICS, which only monitors tools leaving the wholesale crib, is unable to identify important trends in tool consumption at the machining department.

Retail Crib Transaction Monitoring System

The retail crib uses a PC program, written in-house, to monitor the flow of tooling in and out of the department. It, like NPICS, is designed to monitor inventory levels, but unlike NPICS, this program does not provide decision support for the department. The program is used primarily to reduce the need for physically counting the tools in the retail crib. The system does maintain records for each tool transaction involving the crib and can be used as a means of monitoring the flow of tooling to and from machining departments or the cutter grind department. At present it is not used in this capacity because the data it contains is not easily compiled and no analysis tools are included with the system.

General Requisitions and Informal Communication

The heart of the information systems used to monitor tooling is a series of exchange tickets and other, more informal, lines of communication. The general requisition shown in Figure 3-2 is used to facilitate data entry into the retail crib transaction monitoring system, and into NPICS. The tickets serve as controls on the flow of tooling, by requiring that the department receiving the tools take accountability for them. These tickets also provide a mechanism for billing the relevant machining department for the tools it consumes. These costs are grouped under the heading of Other Manufacturing Expense (OME) along with other materials procured by the department, and a statement of OME costs is provided to area managers on a weekly basis. In the head machining departments about 25% of OME costs are tooling.[4] Thus, area managers formally learn about tooling expenditures indirectly, through OME expense.

Most information regarding tool performance and consumption is communicated informally between production workers, cutter grind and retail crib personnel, tool engineers, and department managers. Problems are perceived by one or more of these groups and expressed to managers, who are expected to formulate and direct an effective response. Communication regarding tool management issues is very hierarchical in nature. Almost all tool related decisions move up the hierarchy to the department manager and then back down to subordinates who are instructed to pursue a particular course of action. Unilateral action by workers to address tool management issues is rare.

The truism that tooling problems must first be perceived by a production worker before they can be addressed presents an obstacle to the optimal use of tooling. The threshold

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[4] Interview with Paul Stergar, Chrysler Corporation, Trenton, Michigan, 23 April 1993.

that a tooling problem must surpass at TEP before it is recognized is often quite high. Thus, as with NPICS, quite a lot of tooling must be damaged or destroyed before a tooling-related problem can be addressed. This threshold of perception is so high because of past practice, which promoted tool consumption by the machining department to compensate for other problems, and because the consumption pattern of tools used in a multi-shift operation is non-obvious.

The flow of tool performance information is also hampered by the large tool inventories in place throughout the plant. When cutter grind receives a batch of tools which are over-worn it is impossible to tell when the tools were damaged. This is because after the tool was used in the machining department it probably sat in the job setter's crib for a week, spent another month in the retail crib, and then lay on a table in cutter grind for two weeks. Thus, it is difficult to associate a tool's condition with an event that may have occurred any time over the last two months.

Scrap Tools Provide High Quality Information

A common thread between all of the tooling-information systems used at TEP is that they monitor the scrapping of tools. Unless tools are destroyed no information is generated regarding tool performance. This dependence upon the destruction of tooling (and often machinery and workpieces as well), combined with the slow response times of these systems, makes them ineffective means for discovering tool-related problems before they have reached crisis proportions, both in terms of expense and the threat they pose to halting production.

This problem is compounded by the information destroying nature of inventories. Valuable information regarding the machining process and tool life is lost when a tool which has been removed from the transfer line is put into a pile with other tools where it can no longer be distinguished as a specific item. Valuable information that could have been derived from the tool's condition and operating history is lost when tools are stored and handled in this manner.

3.3 Performance Measures for Tooling in Head Lines

Tooling performance in the engine head machining departments, and throughout the plant, is reported on a formal basis through the Other Manufacturing Expense (OME) component of the traditional flexible budget system used throughout Chrysler. The OME for each department is calculated on a weekly basis and provided to the plant's department managers. As a means of evaluating tool performance OME is relatively ineffective. It is a coarse measure which contains all non-labor costs for the department. Only a fraction of these costs are tooling-related. Further, by the time an area manager receives a report on OME costs he has probably been made aware by personnel in his department about tooling problems which would significantly impact this area of his budget.

More relevant measures of tooling performance are not available to area managers or tool engineers on a regular basis. While area managers receive detailed lists of tools "bought" by his department from the wholesale crib, the value of these lists is reduced by their inability to reflect hidden inventories, and by the manner in which the tools are identified in the list. Production personnel identify tooling by its location in the transfer line, or a physical description of the tool (e.g. - "the 1/2 inch tap used in operation 20R, station 14L") rather than by tool number or Chrysler code number. Thus, to make use of the voluminous lists of tool purchases, an area manager needs to "translate" the information into a more recognizable form. Rarely do managers have the time to perform such activities, particularly when a line might use 100 different types of tools, and consume several hundred per week. Furthermore, these lists do not identify any trends in tool consumption. In short they provide managers and engineers with data, but not information.

More useful information on tool performance can be provided to managers and engineers by NPICS and tool stores personnel - the group that oversees NPICS and the purchase of material. But, compiling the consumption history for a particular tool is time consuming and only somewhat relevant, because of the deficiencies of NPICS previously described. Also, before managers would ask for such information regarding a problematic tool, the tooling problem in question has to have become glaringly apparent. The manager's goal is to correct the tooling problem immediately, and the overarching causes of that problem are of little concern. This is symptomatic of the "fire-fighting" mode that managers and engineers at TEP typically find themselves in.

Five Tooling Performance Measures

We worked to develop better means of evaluating the efficiency with which tooling was used at TEP. The goal of this development was two-fold, [1] to evaluate the efficiency of tool management in its present and future forms at TEP, and [2] to provide managers a high quality measure of tooling performance without overwhelming them with reams of data.

The remainder of this chapter outlines the nature of the five measurements, and describes the methodology used in applying these measures to TEP's cylinder head lines, and the tool management systems used in them. A prediction of tool performance in the 3.5L head line, if operated under existing tool management schemes, was also made. The five measurements are: float, float cost, tool demand, premium purchases, and the opportunity cost of lost production.

Float

Float measures the amount of tool inventory stored throughout the plant. This includes the inventories in the wholesale and retail cribs, the cutter grind department, job setters crib, and "hidden" inventories in the machining department itself. Tools in machinery are not considered in this measure.

Float can be calculated for an entire department, or it can be determined for each tool-type. The float for each type of tool (e.g. - mill, drill, tap) affords a more accurate representation of the inventory picture because the types of tools used by each department varies greatly depending upon the part being manufactured. Measuring float by tool type is also more accurate because consumption patterns differ by tool type.

When measuring float for each tool type the measure must reflect the department's production rate, and the number of spindles in which a particular tool is being used. We would expect a tool that is being used in six spindles to require more inventory than one that is used in two spindles, for example. Likewise, a department that manufactures 2000 parts per day should be expected to have more inventory than a department that manufactures only 1000 parts per day.

The measure of float volume used for tool type i in department j is represented by:

$$FLOAT_{i,j}=\Sigma_k\{(INV)(PCS)/[(VOL)(sqrt\{N\})]\}/TOT$$

where:

k represents a particular T# or code # of tool type i in department j (k ranges from 1 to TOT)
INV = inventory of tool k of type i in department j
VOL = production volume per day in department j
PCS = tool change frequency of tool k of type i in department j
N = the number of spindles in which tool k of type i is used in department j
TOT = the total number of different T#s of type i used in department j.

The components of FLOAT other than INV adjust INV so that tool inventory can be compared across departments. A low value of FLOAT is desired, and a higher value indicates that tools are not managed as efficiently. It is important to note that this measure allows us to judge the tool management system independent of the department in which the tools are used. Our goal is to judge the mechanisms in place for handling tools, not the machining operations themselves. This is an important distinction because the age and efficiency of equipment varies widely throughout TEP, and because a stumbling block to expanding the newly developed tool management system lies in the popular belief that any improvement of tool performance in the pilot is a function of the fact that the department is new, rather than it being a result of improved tool management techniques.

More specifically, FLOAT is proportional to PCS and 1/VOL because we want to correct inventory for the effects of long lived tools (which should lead to lower inventories), and for differences in production volumes (higher production volumes should lead to increased inventories of tools). The dependence of FLOAT upon $N^{-0.5}$ reflects the fact that when a particular tool is used across multiple spindles, variations in each spindle's behavior average out to some extent. Thus, the net amount of inventory required to support their operation is less than if tools were maintained separately for each spindle, as per the central limit theorem.[5]

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[5] Robert Hogg and Johannes Ledolter, Engineering Statistics (New York: Macmillan Publishing Company, 1987), p. 140

It should also be noted that the value for PCS is an estimate based upon published values created when the department in question first began operation. The actual value of this variable is unknown for all but the TTM pilot department.

Under an ideal tool management system the value of FLOAT would remain constant for variations in PCS, VOL, because these changes would be balanced by changes in INV. The overall effectiveness of a tool management system is measured by the value of FLOAT, the lower the better. Figure 3-6 presents the values of FLOAT for drills and mills for TEP's 2.5L 4-cylinder, 3.3L V-6, and TTM pilot cylinder head lines.

Float Cost

FLOAT is accompanied by an aggregate measure for the entire department. Float Cost measures the department's total inventory relative to the inventory designed for that department at its inception. The value of the float, FLOAT$, is represented non-dimensionally as

$$\text{FLOAT\$}_j = (\text{Total Inventory Value})/(\text{Predicted Inventory Value})$$

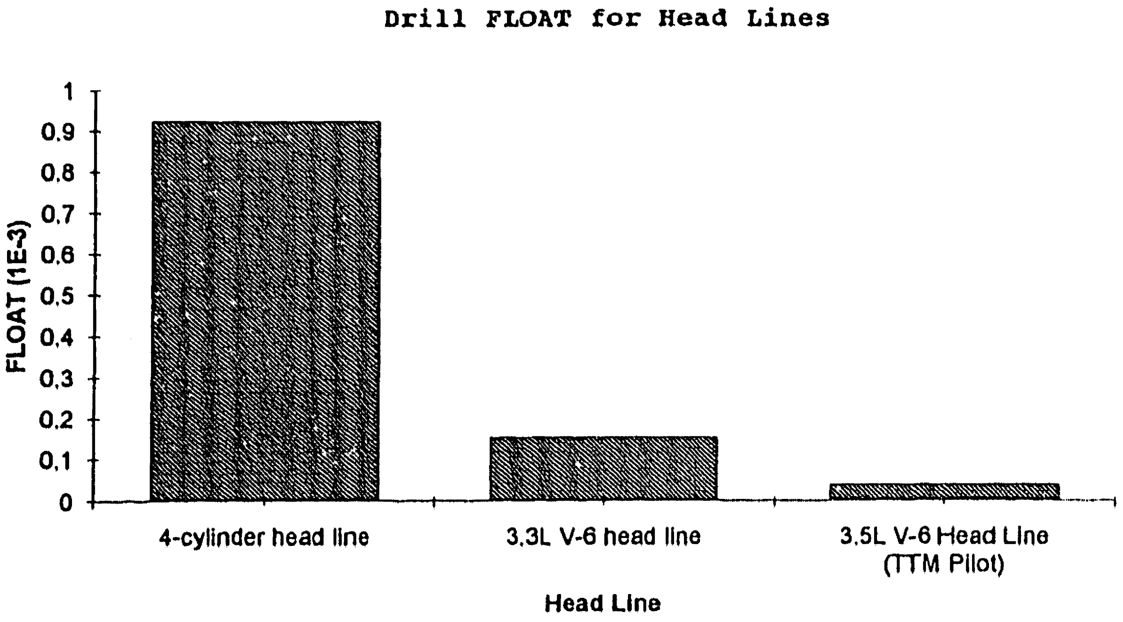
where j is the department in question.

This measure essentially compares the tooling performance of the department to the performance predicted by the department's float sheets. These sheets predict the amount of tooling that will be required to support the line, and dictate the location of that inventory. To calculate FLOAT$ we physically inventoried the tools in the department, established their value, and compared this to the cost of the inventory as detailed in the float sheets for department j. While this measure does not correct for differences in department performance, it is more easily understood and communicated than FLOAT.

We calculated the value of float for Department 424, the four cylinder head line, which uses typical tool management procedures. We found that

$$\text{FLOAT\$}_{424} = 4.2$$

So, department 424 possesses inventory valued at 4.2 times the amount specified by the float sheets. When a new line begins operating the value of FLOAT$ equals 1 because only the tools detailed on the float sheets are bought.



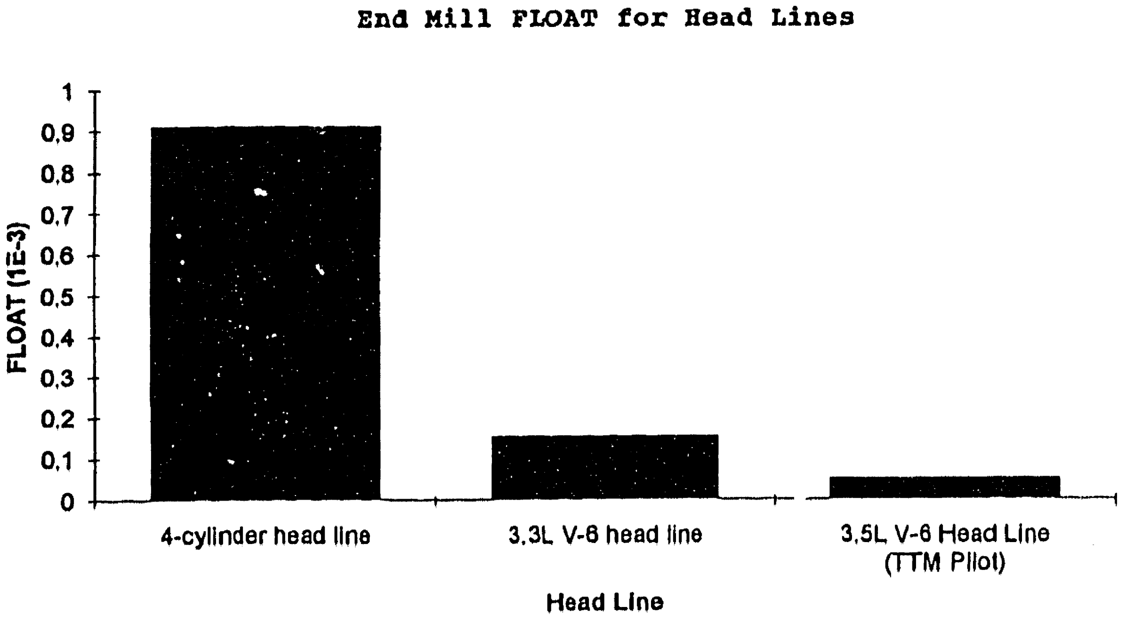


Figure 3-6: FLOAT values for drills and end mills in each of TEP's cylinder head machining departments

But, as production ramps up, and tooling problems arise, the mechanisms previously discussed contribute to growth in tooling inventories. In the case of Department 424 it took twelve years to go from a value of one for FLOAT$ to quadruple its initial levels. Our experience tells us that in other departments the value of FLOAT$ is higher than 4. An argument can be made that a value of FLOAT$$_j$ greater than one doesn't indicate excessive inventories, but instead reflects inadequacies in the construction of the department's float sheets. Regardless, if department 524, TEP's new head line, were to experience inventory growth similar to department 424, the department could expect inventories to exceed float sheet values by over $260,000.

Tool Demand

In addition to tracking tool inventories it is useful to monitor the amount of tooling that is consumed by a machining department. In a department with a successful tool management system we would expect to see tool demand decrease over time as the department becomes more proficient at monitoring and controlling its tooling. Tool demand would decrease as a result of [1] lower scrap rates for tooling - tools are being replaced before breakage, and [2] longer tool lives - tools with longer lives are employed. This measure reflects the success or failure of the tool management operation regarding the roles of tool engineering (e.g., how well do tool engineers upgrade tool performance?), and machining department personnel.

Tool demand can be represented as

$$\text{DEMAND}_j = (\text{Tools Purchased})/(\text{Production Volume})$$

where the tools purchased and production volume are measured over a set increment of time, typically one week. By tools purchased we are referring not to the tools that are purchased by TEP from vendors, but the number of tools purchased by the department from the wholesale crib. This distinction is necessary because the purchase of tools from vendors is dictated by lot-size concerns which would prevent us from monitoring the effectiveness of a tool management system at improving the use of tooling. DEMAND can not be used to compare performance across departments because of the great number of operational differences from one machining department to another. But, over an extended period of time the measure does indicate the degree to which a machining department is able to improve the performance of its tooling.

Premium Purchases

When a department is breaking multiple tools of the same type over a short period of time, or when scrapped tools are not removed from circulation, but instead are discovered when placed into the transfer line, orders for new tools must be received from vendors with minimum lead times to prevent tool shortages. This drives up the price per tool, often in excess of 100% of its base price.

The premium purchases measure reflects the amount of money spent by the plant on behalf of a machining department to rush needed tools into the plant. It is represented as

$$\text{PREMIUM}_j = (\text{dollar value of premium purchases})_j$$

and is taken over a fixed time period, such as one year. A low value of PREMIUM indicates a minimal number of successive breakages of a particular tool. Thus, this measure reflects the ability of the tool management system to identify, and correct, tool-related problems before they recur.

At present, premium purchases are not billed to a department's OME expense. Instead these expenditures are billed to a plant-wide expense account. As a result there is little motivation for department managers to avoid premium purchases, as they don't directly pay for them. Unfortunately, because these expenditures are grouped into a single account it is difficult to look at historical records and determine the value of premium purchases for a particular department. As a result we estimated the premium purchases of departments 424 and 624 by assuming that the level of premium purchases was equal for all 31 of the plant's machining departments. We then divided plant-wide premium tooling purchases for July 1991 - July 1992 by 31 and obtained a value of approximately $28,000. Compared to the specification sheet estimate for 524 inventory of $128,000 this is a significant figure.

While data regarding premium purchases specifically for departments 424 and 624 was not available this measure was used to track performance in the department 524 tool management pilot. These results are presented in Chapter Six.

Opportunity Cost of Production

When a tool breaks on the line, or when it is changed routinely during a shift where production occurs, some production is lost. To estimate the cost of lost production due to these scheduled and unscheduled tool changes we can look at the allocated tool change time, and down-time due to tool breakage on a departmental basis. The opportunity cost of production can be measured in dollar terms by associating over-time labor with the lost production. This is a good estimate because when a department doesn't meet its production quotas it must make-up for the lost production with over-time labor which is billed to the department.

We can represent this measure as

$$OCP_j=(HOURS)(STAFF)(RATE)$$

where

HOURS = number of hours of production lost due to tooling per annum
STAFF = number of workers per shift
RATE = over-time pay rate

Based on a study performed by Lamb, the manufacturer of TEP's head lines, during the first year of 624's operation, almost 11% of scheduled production time was lost as a result of scheduled and unscheduled tool changes. If a similar amount of down-time were to be experienced in department 524 it would cost TEP almost $350,000 in over-time labor per year.[6]

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[6] Ken Rommelaere, 3.3L Cylinder Head Machining Performance Study (Warren, Michigan: Litton Industrial Automation, [1990]), p. 13

4.0 Trenton Tool Management System

This chapter begins with a discussion of the state-of-the-art in tool management at mass production metal working facilities. Three examples are used to illustrate popular approaches. The remainder of the chapter details the design of the Trenton Tool Management system. This includes a discussion of the overarching principles guiding its development, followed by an overview of the flow of material and information in the system.

4.1 Models for Tool Management: Block Tool Changes and Vendor Inventory Control

The tool management system in place at TEP is typical of mass production metal-working facilities. As described in Chapter 3, tools are normally removed from the transfer line when they are broken, or when poor quality parts are being produced. This creates scrap workpieces, and also leads to a large number of scrapped tools. The productivity of the transfer line is also reduced because the time used to replace a worn or broken tool cannot be used to machine parts. Block Tool Change (BTC) systems address these problems by scheduling the replacement of a large number of tools in the transfer line at predetermined intervals. When possible, tool replacement is performed on a shift when the transfer line is not scheduled to run. For machining departments that run on all three shifts, changes are made to the production schedule, or the line is shut down for a period of time at the beginning of one or two shifts each day to facilitate tool changes.

Block tool change systems are designed to impact the plant's tool performance system locally, at the level of the machining department. Typically, BTCs do not take a systemic view of the tool management environment. The roles of cutter grind, the wholesale and retail cribs, and tool engineering are not addressed by pure BTCs, and so improvements in tool performance come as a result of less tool breakage rather than complete management of the tooling system. While the non-systemic approach of BTCs has its faults, BTCs are improvements over conventional tool management practices, and represent a good springboard for realizing more effective systems.

The principal benefits initiated by Block Tool Change systems are 1] less tool breakage, 2] less manufacturing scrap as a result of broken or over-run tools, 3] less tool consumption due to decreased tool breakage and fewer over-run tools, and 4] the opportunity to lower tool inventories as a result of same. The principal weaknesses of BTC systems are [1] the static nature of their tool change scheduling methodology, [2] a lack of integration with other tool management functions, principally cutter grind, [3] an inability to aid in the identification of poorly performing tools, and [4] the inability to address the majority of tool inventories as present in the wholesale and retail cribs.

Kenosha Engine Plant's BTC

Chrysler's Kenosha Engine Plant (KEP) initiated a BTC system on its 6-cylinder block line, a thirty year old machining department, in 1991. Made possible in large part by the efforts of Dean Samuels, a supervisor in the cutter grind department and a Tool Engineer, this system enabled the department to meet its production goals running sixteen hours per day, five days per week, whereas prior to implementation of the BTC the department ran twenty hours per day six days per week.[7]

The BTC used at KEP changes groups of tools every third shift based upon a pre-set schedule. Because production volumes are constant in this department KEP is able to predict with a high degree of accuracy when a tool will reach its tool change frequency. The tool is then removed on the off-shift closest to, but not exceeding, this tool change frequency. For example, if the department made 1000 parts per day, and the tool change frequency for a tool was 3500 pieces, the tool would be removed from the machine after 3000 pieces so that it would not be over-run, which would increase the likelihood of tool failure. A spreadsheet is used to keep track of the tool change schedule for the department, and a sheet listing the tools to be changed is printed out each day. Tools are transported by cutter grind personnel to secured storage in the department. A job-setter then changes all of the required tools each evening. Tools are transported in compartmentalized plastic totes to separate them from one another and to facilitate easy transport and handling. The tool change scheduling software is primitive in that it does not take into account the capacity of the job-setter when dictating which tools should be changed. As a result, every few weeks too many tools are scheduled to be changed. When this occurs some tools are not changed until a later date, causing them to be over-run.

Because the BTC greatly reduces the amount of tool breakage, all tool inventories were removed from the production floor. These tools were transferred to the retail crib and the

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[7] Interview with Dean Samuels, Chrysler Corporation, Kenosha, Wisconsin, 15 July 1992.

job setter crib, rather than being eliminated through attrition. By removing inventory from the floor, over-run and poor quality tools are much less likely to enter the transfer line. Interestingly, the BTC had the effect of increasing the volume of tools that cutter grind had to process because rather than break tools and replace them with new ones, many more tools are reclaimed for regrinding. This cutter grind capacity problem is presently being addressed at KEP.[8]

The KEP BTC system does not alter the way in which tools are stored at the retail or wholesale cribs. Nor does the system change the way material is handled in the cutter grind department. Also, the system does not directly address the underground tooling economy, which expands when problems arise in the line. However, it does so indirectly by reducing the number of tooling problems that occur.

Figure 4-1 illustrates the change in tool inventories and flows created by the BTC system at KEP. The KEP block tool change system aims to reduce the number of tool changes that occur during those periods when the block department should be manufacturing parts. It has done this successfully, increasing departmental efficiency by 25%.[9] Unfortunately, this improvement is largely a one-time change. The KEP BTC system does not contain mechanisms for formally evaluating tool performance and identifying areas of greatest tool expense. The system also depends upon well set tool change frequencies to ensure that tools are used as long as possible between regrinds, and does not permit problems to be tracked on a spindle-by-spindle basis. As a result, the system's ability to foster continuous improvement in terms of production quality and cost is limited. In summary, the tool management environment created by KEP's BTC is characterized by significantly lower amounts of tool-related down-time, but tool inventories are not significantly lower relative to the prior environment.

Expanded Block Tool Change at Ford Essex

Ford's entire Essex engine plant operates with an expanded BTC system. Beyond the use of organized off-shift tool changes, Essex has centralized all tool inventories in a single location adjacent to its cutter grind department. Tool heights are also set at this location for the entire plant. As a result, its inventories appear to be significantly less than those of either Chrysler's Kenosha or Trenton engine plants.[10]

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[8] Ibid

[9] Ibid.

[10] William Mulhern, Memo: Essex Trip (Trenton, Michigan; Chrysler Corporation, [1992]), p.1

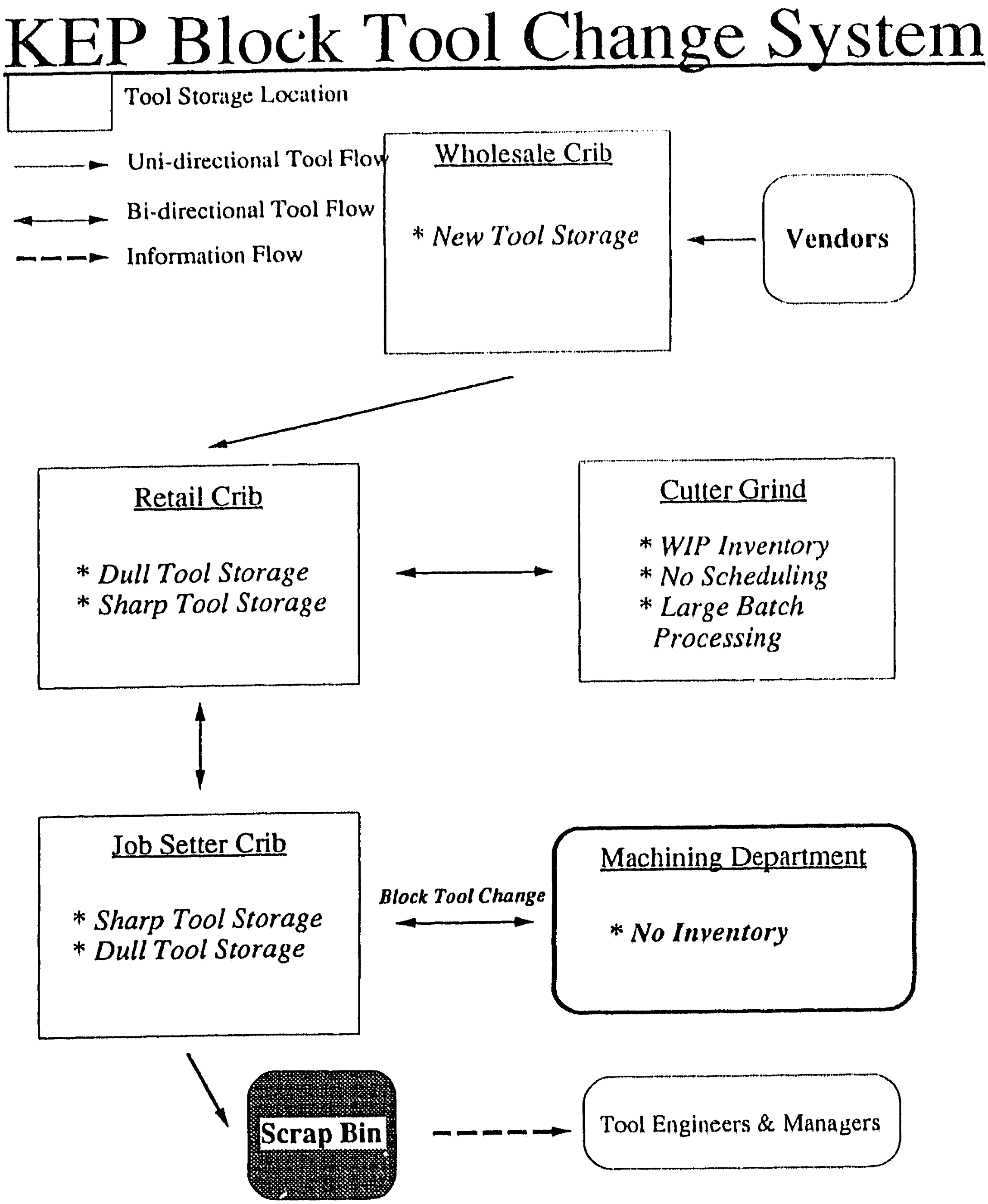

Figure 4-1: Flow of material and information in the Kenosha Engine Plant block tool change system (KEP BTC). This system removes inventory from the floor. This is significant because such inventories can represent up to 50% of the total inventory. Unfortunately the KEP BTC does not eliminate these inventories. Instead, it stores them at another location, and the total inventory level is not dramatically reduced.

Using a computerized tracking system, tool change schedules are generated automatically for each machining operation, and the flow of tooling in and out of the crib area is monitored. The flow of tooling between the retail crib and cutter grind is similar to that of both KEP and TEP. Tools are ground in large batches of indeterminate size. Thus, the inventory levels at Essex are not as low as they could be because tools are stockpiled in order to generate large lot sizes for grinding.

Essex's tool management system represents the next, logical, step from Kenosha's block tool change system. Control over tool inventories has been integrated back from the machining department to include what formerly were job setter and retail crib inventories. The integration of job-setting and retail crib functions has improved the reliability with which tool heights are set, and has reduced the investment in capital equipment required to outfit each machining department with its own job setter crib. Complete control over tool inventories at Essex means that managers and engineers are more likely to become aware of tool-related problems before they become crises. Tools can not be fed into a transfer machine without interaction between the machining department and the central tool crib, thereby triggering notification of department managers and tool engineers.

It is interesting to note that the organizing principal behind both KEP's and Essex's tool management systems is to increase management control over tooling, and to place the mechanisms for improving the department's tooling performance in the hands of managers rather than hourly personnel.

Vendor Inventory Control

Another trend in tool management is for a plant to contract all of its tool management functions to an outside firm, usually a manufacturer of tooling. This firm's operations effectively replace the retail, wholesale and job setter cribs, while leaving the plant's cutter grind operation in place.

An example of such a service is provided by GTE Valenite, a maker of insert tooling for metal working applications. They provide the required amount of tooling to the plant, and ensure that tools are always available to meet the needs of the machining departments. In addition, all tooling is either purchased through or manufactured by Valenite. Thus, the contracting firm has a high level of control over both the inventory levels at the plant, and tool sourcing. Figure 4-2 illustrates how this system would impact tool management at TEP.

Adoption of such a system allows the plant to avoid the sometimes difficult dealings with its workforce by replacing them with a contractor whose employees are not unionized. Payment is made to Valenite for each tool purchased, plus a service charge for the tool management functions they provide. In practice, the tool management systems these vendors provide are no different than the systems presently in place at TEP.[11]

We feel that adopting such an arrangement will not improve tool management at TEP, or any other Chrysler facility. Instead it will shift the burden of bloated inventories and inefficient tool processing to the vendor, who will bill Chrysler to reflect these costs plus a profit margin. In the end, Chrysler will not have gained improved performance, and will have ceded control over an important element of production - tooling. Further, such a change is seen as the first step towards eliminating all tool-related operations in the plant, including the cutter grind department and tool engineering. This would eliminate potential sources of competitive advantage for Chrysler, namely, superior manufacturing tools and process knowledge. In our view, vendor inventory control is disadvantageous because [1] other, potentially superior suppliers can be locked out of the plant, [2] the plant will have little ability to dictate inventory policy, or take direct action to reduce costs, and [3] this solution avoids rather than addresses union-management conflicts and manufacturing problems that must be solved to run a profitable plant.

4.2 Trenton Tool Management Design Approach

When we began working to develop a tool management system for use at TEP we were met by many preconceived notions about the form which the system should take. TEP managers, and Advanced Power Train Manufacturing Engineering (APTME), a steering group, envisioned a tool management system much like that used at Ford Essex.[12] Managers from TEP and APTME had spent significant amounts of time at Essex, and correctly believed that the system in use there would provide significant benefits to TEP, and throughout Chrysler. In fact, money had been allocated to purchase equipment to facilitate the construction of a system like that at

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[11] Tom Bohn, Letter; Valenite Tool Handling Systems and Cribs, (Troy, Michigan; GTE Valenite [1991]), p.3-8

[12] Anne Wright, Memo; Block Tool Change and Tool Management Plan Outline (Highland Park, Michigan; Chrysler Corporation [1990]), p. 1

Vendor Inventory Control

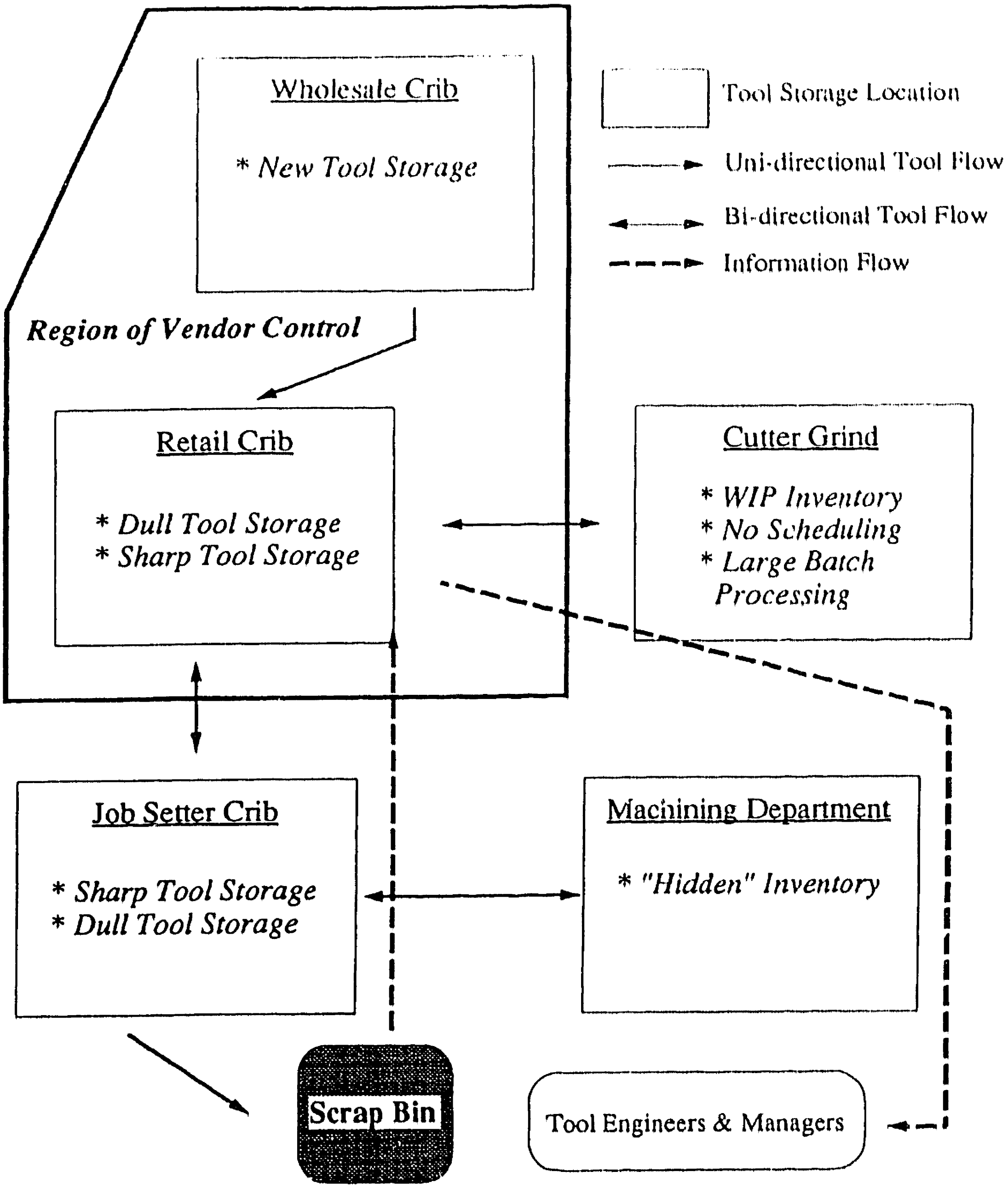


Figure 4-2: Under vendor inventory control the operation of the wholesale and resale cribs is no longer under the plant's control. The lead vendor manages these areas and interfaces with all other tool vendors as well. Engineers and managers must depend upon the lead vendor for information regarding tool performance and costs.

Essex. Royal Design and Manufacturing, a Madison Heights, MI based firm had been contracted to provide the software and hardware required for such a system.

As such we began our work assuming that we would implement a block tool change system for use at Trenton. But, as we explored the nature of tool management further, we became convinced that a block tool change system was not the best solution for TEP.

We used the measures presented in Chapter 3 to rigorously define the problem of tool management. By using quantitative data provided by these measures, and qualitative data obtained from extensive discussions with personnel in all areas touched by tool management (e.g., tool cribs, cutter grind, tool engineering, etc.) we derived a systemic picture of the faults of tool management as practiced at TEP. A complete listing of the problems perceived in current methods of managing tooling is presented in Appendix A.

Part of the reason that the BTC system is so appealing is that it can be built around the existing culture at TEP. The BTC takes the organizational structure at TEP as a given, and requires little organizational redesign. Workers' jobs are not redefined, and the routines of involved workers change little. Under a BTC, Job Setters, for example, would perform all of the same functions they do now, only on a different shift. Cutter grinders would grind tools using current techniques, and the wholesale and retail crib would operate no differently either. While there are benefits to working within an organization's structure, we were convinced that in this case, pursuing the path of least resistance would prevent us from achieving the benefits of a more comprehensive tool management system. Such a system needs to be designed from the bottom-up, without preconceptions regarding the division of labor within the plant.

Design Approach

Our goals in designing the tool management system were to reduce total tooling costs, and to create a means of continually improving tooling performance. In order to achieve these goals each tool in the system must be treated as a single entity, with a well documented history. By treating each tool as a separate item we can more easily observe trends in tooling performance and identify those tools which are not performing adequately. It also makes it easier to control tool consumption.

Another reason for wanting to treat each tool as a separate entity was that in a block tool change large groups of tools are changed at the same time, regardless of their recent history. For example, if a machining station uses eight T-54 drills they will be changed in a single "block" at the same time, every 3,400 pieces for example. Even if three drills break at 1,200 pieces, all eight will be removed when the five which didn't break reach a count of 3,400. As a result, 2,200 pieces worth of life is wasted on each of the three drills which were removed prematurely. The benefit of grouping tools into blocks is that it requires less labor to change and handle the tools.

Treating each tool as a separate item has three major ramifications. First, we need to limit the amount of tool inventory in the system. Otherwise, managing the historical data for each tool becomes an overwhelming task. Second, we need to establish reliable methods for collecting and interpreting the information associated with each tool so that it can be used to improve tooling performance. Finally, we need to ensure that adequate man-power exists to handle tools on an individual basis. This is an issue because when we treat tools as independent units many of the tasks required to change a tool must be performed multiple times, instead of just once, as with a block tool change. Referring back to our T-54 example, if we change the eight tools at the same time, we need to pull back the station head only once every 3,400 pieces of production. If on the other hand we changed one of the eight tools each day (because their history had pushed each tool's life out of phase with the others, for instance) we would have to pull back the head eight times more often than if the tools were changed at once. With regards to scheduled tool changes it is important to find a balance between grouping tools into blocks and treating each tool as an individual entity.

Starting with the assumption that treating each tool as an individual entity would provide benefits in terms of reduced tool costs, and improved tool performance, we designed a material flow for tooling. Initially this flow was designed on a functional basis. We asked, "what operations need to be performed on each tool between the time it is removed from the transfer line and when it is ready to be reinserted?", and, "how do we track tools as they proceed through this series of operations?"

Once we were satisfied with the general flow of material we looked at each function and determined which organization in the plant could best carry out the required work. At this point we began to take into consideration restraints regarding the type of work that different classes of hourly workers can perform. Man-power and time constraints were also evaluated at this stage of the design process to ensure that the tool management system would have enough capacity to handle the expected tool flows. Interaction with hourly personnel in affected departments, and with managers and UAW officers, was a critical element in flushing out the details of the tool management system design.

Throughout the development of the physical tooling flows we kept in mind the type of information that we wanted to provide to tool engineers and area managers to improve tool-related decision making. Department managers and engineers told us what information they would find most valuable. This enabled us to effectively integrate the collection and distribution of tool-related information with the management of physical tooling.

The process of designing this system took approximately two months. The following two sections outline the final system design, which was the end-result of these efforts. Relevant iterations between the beginning of the project and the final design will be discussed in the context of the pilot implementation, in Chapter Five.

4.3 Material Flow in Trenton Tool Management

The following describes the path tools follow in the Trenton Tool Management system. This tool flow forms the basis of TTM, and its characteristics dictate the overall structure of the system. The tool flow begins with an off-shift tool change and traces the path of a tool until it is ready to be used in the transfer-line again. The flow of material was designed to insure that each tool could be linked to the time and place where it was used to machine parts, and that the inventory of tools could be minimized. The other aspects of TTM, including information flow, and personnel deployment, grew out of this tool flow.

Off-Shift Tool Change

Figure 4-3 details the sequence of operations performed on each tool in the tool management system. The process begins at point 'A' under the heading "Second Shift Activities" in the figure. 'A' represents the beginning of an off-shift for the department in question. For the case of the pilot department, which initially is running on one shift, 'A' is the beginning of the second shift. At 'A' the second-shift job setter has received a list of all the tools to be changed that evening, and the tools have been arranged in a series of plastic trays to facilitate their transportation from the job setter crib to the machining department. Tools are identified by their location in the transfer line.

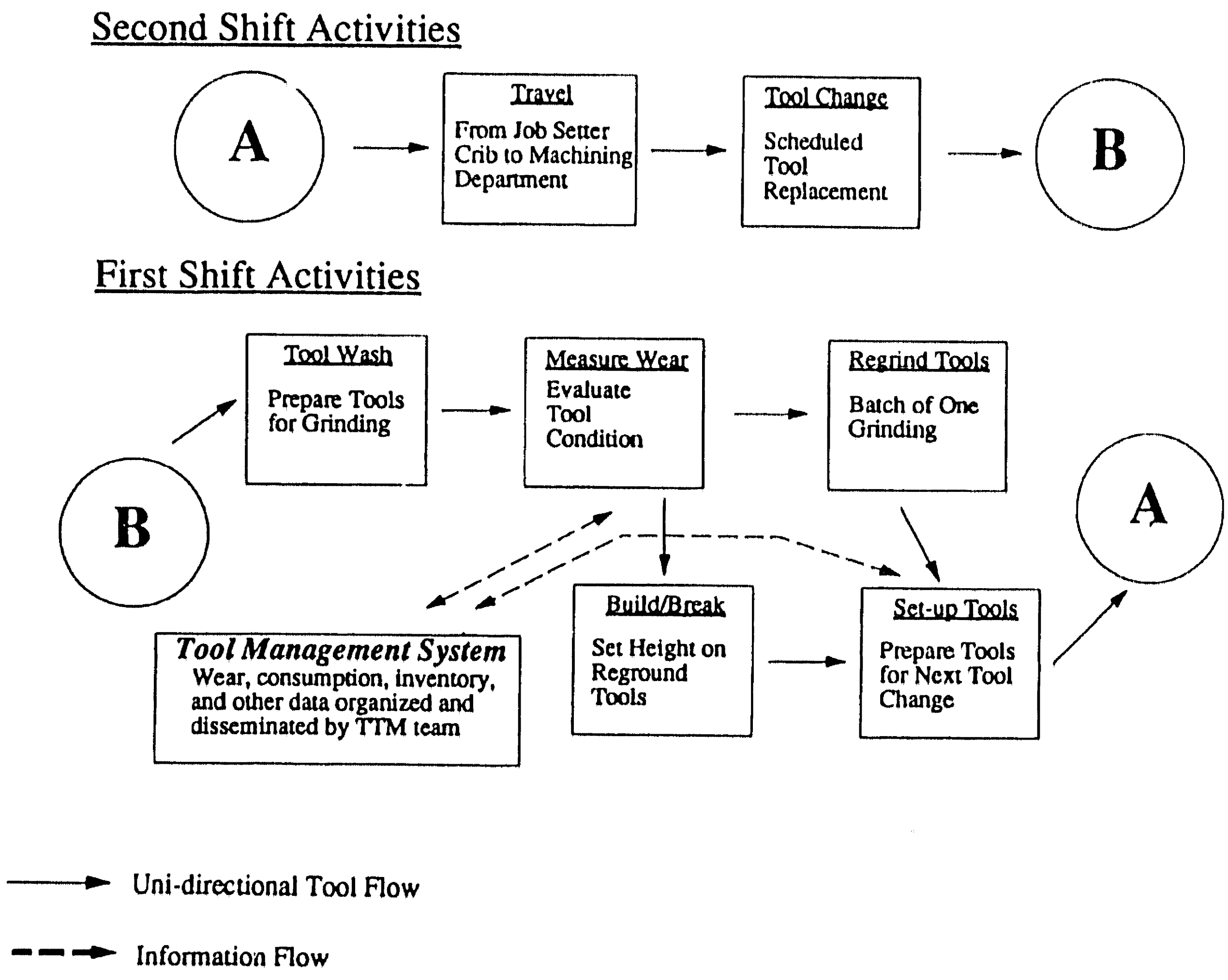


Figure 4-3: Flow of tooling through Trenton Tool Management. Two flows are indicated, one for the off-shift tool change, and one for the first shift, during which time tools are reground and prepared for use. Combined, these two flows form a continuous loop through which tooling moves.

For example, "30R-10LH-407" indicates the tool which is used in operation thirty rough, station ten left hand, spindle 407. An example tool change list is presented in Figure 4-4. The tool change list is generated based upon the number of parts made by the department each day with adjustments for tool breakage and unscheduled tool changes. The tool change list is generated dynamically, takes into account unscheduled tool changes, and is constrained by labor capacity.

The second shift job setter changes each of the tools on the list. At this point the trays serve as a visual control on the tools which should be changed. Compartments in each tray are labeled as per the above convention, and so the job setter has a means of double checking the tool change list he has been provided. In order to identify the proper spindle on the machine station in question, the job setter consults a spindle location book. This book was derived from the transfer line process prints, and an example page is shown in Figure 4-5.

When the job setter removes a tool from the transfer-line he exchanges it one-for-one with the appropriate tool in the plastic tray. Once he has changed the tool, a worn tool now resides in the slot where the sharp tool previously lay. By changing the tools in this manner, and ensuring that the tools remain with the tool tray, the exact spindle from which a worn tool came from can be determined. This linkage between tray and tool takes on great importance later in the flow.

Once the second shift job setter has changed all of the tools scheduled for that evening he stacks the tool totes, which now contain only worn tool assemblies, on a table in the aisle near the transfer line. This represents point 'B' in Figure 4-3.

Tool Transport

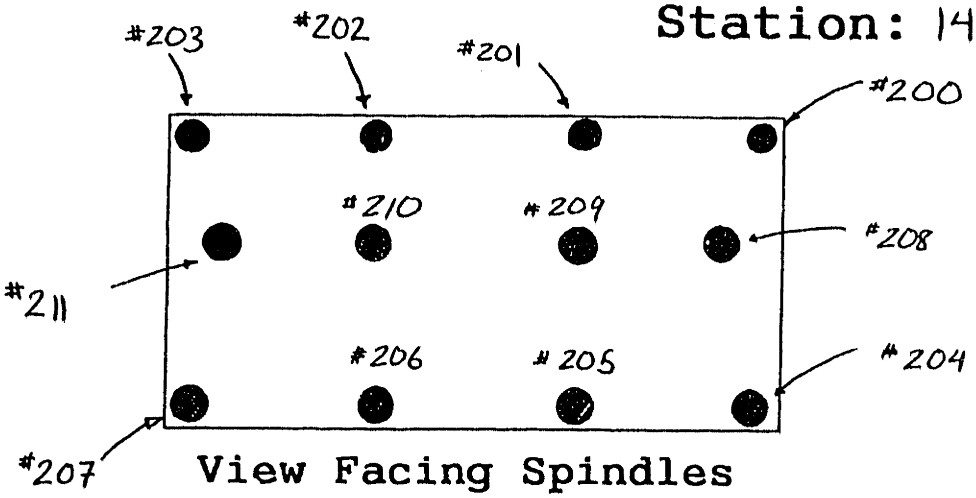
At the end of the second shift a worker drives to the department with a flatbed vehicle and transports the worn tools, still in their trays, to the 524 Job Setter Crib. This crib is not located in the machining department, but rather next to the cutter grind department, for reasons that are discussed later. The tools are then stacked up in the crib, where they await the arrival of the first-shift job-setter.

Tool Change List			9/16/92	WEDNESDAY		
Set	1		Change:	9	Changed?	Checked?
40R	14LH	203				
40R	14LH	204				
40R	14LH	205				
40R	14LH	206				
40R	14LH	207				
40R	14LH	208				
40R	14LH	209				
40R	14LH	210				
40R	14LH	211				
40R	16LH	214				
40R	16LH	216				
40R	16LH	218				
40R	17LH	208				
40R	17LH	209				
40R	17LH	210				
40R	17LH	211				
40R	17LH	213				
40R	17LH	215				
40R	17LH	217				
30R	2LVA	400				
30R	2LVA	401				
30R	2LVA	402				
30R	2LVA	403				
30R	2LVA	404				
30R	2LVA	405				
30R	4LVA	231				
30R	4RVA	300				
30R	4RVA	301				
30R	4RVA	302				
30R	4RVA	303				
30R	5LVA	231				
30R	7RVA	307				
30R	7RVA	308				
30R	7RVA	309				
30R	8RVA	307				
30R	8RVA	308				
30R	8RVA	309				
30R	8LVA	231				
30R	10RVA	304				
30R	10RVA	305				
30R	10RVA	306				
30R	10LH	407				

Figure 4-4: Tool change list for September 16, 1992. The first shift job setter uses this list to prepare the necessary tools for the tool change, and the second shift job setter then uses it to manage the tool change during the second shift.

Spindle Identification Sheet

Operation: 40R
Station: 14LH



Operation Description

Tap drill (8) Cover holes
#200 thru #207.
Drill rocker shaft mounting holes
#208 thru #211

REF: 4315806-L-4009

Figure 4-5: Spindle identification sheet for Operation 40, Station 3LH. The second shift job setter uses this sheet to locate the position of tools which are supposed to be changed as part of the tool change. Additional sheets, one for each station, are compiled into a book for easy reference.

Tool Washing

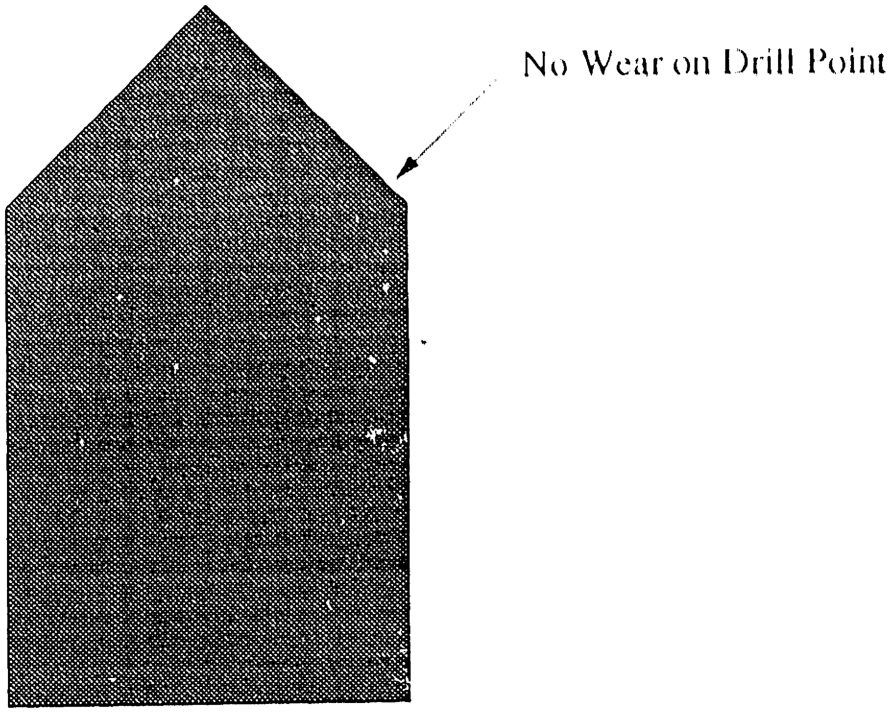
Once the trays containing worn tools have been returned from the transfer line they are prepared for regrinding. The tools are not removed from their holders or from the tool trays. Instead the entire tray is placed into a washer, which removes caked on debris and oils. It is important that the tools remain in the trays because each tool-holder assembly is not individually marked to identify where it was used in the transfer line. To do so, using bar codes or embedded computer chips, would be prohibitively expensive.

Wear Measurement and Pre-Grind Inspection

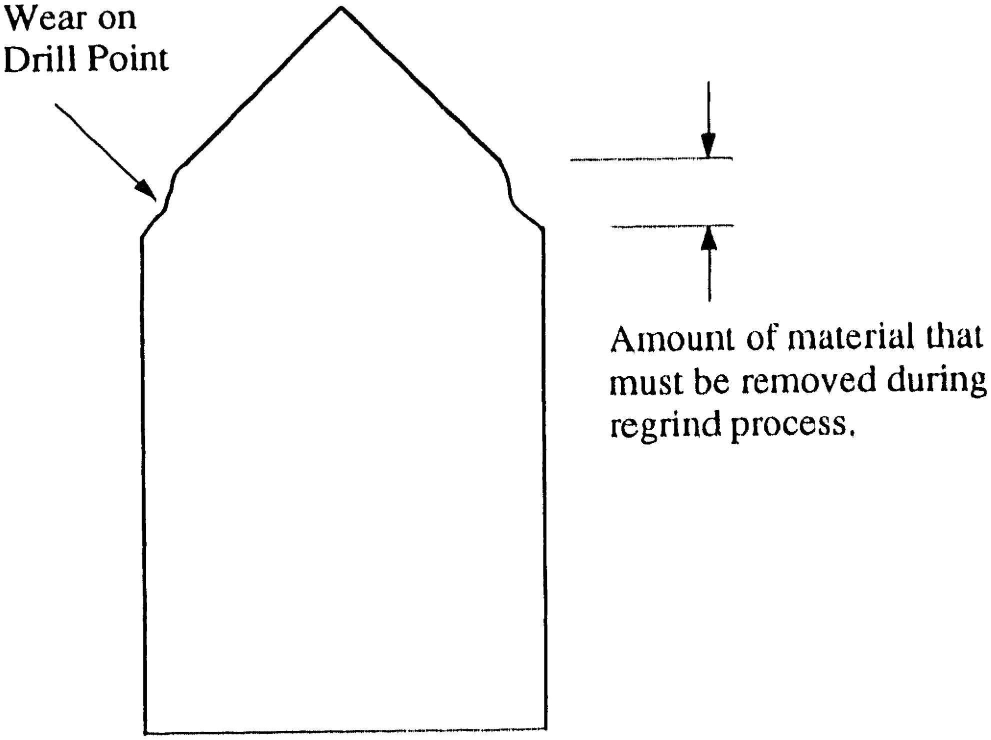
Once the tools have been washed they are inspected for wear. This measurement is not quantified on the basis of crater wear, edge wear or any of the other scientific categorizations made for tool wear. Instead, it is quantified in terms of the length of the tool, measuring from the tool tip, that will have to be removed during the regrind process. [Figure 4-6] This is the relevant measure because it determines the useful life of the tool between regrinds. This value can then be related to the tool's present tool change frequency. If the tool edge is completely eroded the tool was probably in the transfer line too long. Thus, its tool change frequency should be reduced. If the tool exhibits very little wear then the tool change frequency for the tool in question was too low and the tool can be left in the machinery longer the next time.

By evaluating each tool in this manner, high quality data regarding tool performance trends can be accumulated. In order for this process to be effective we must be certain of the identity of the tool being measured. Thus the tools are kept in the plastic totes as they proceed through this process so that tool wear can be correlated with each tool on a spindle by spindle basis.

Tools are also inspected at this point to insure that they have not become undersize during their stint in the transfer line. This is done to prevent any scrap tools from being reground. This is essential because regrinding is the bottleneck of the entire process and we can't afford to waste any grinding capacity.



NEW DRILL PROFILE



WORN DRILL PROFILE

Figure 4-6: Comparison of tool tip on sharp and worn tool. Depending upon the condition and design of the tool, wear can develop in several places including the tool tip or flank, as shown. To be reground, the wear must be totally removed, reducing the overall length of the tool.

Tool Grinding

Once the tools have been measured for wear they are passed on, still mated to their holders, and in the proper trays, to be reground. Unlike past practice, where tools sat for weeks before being reground, under TTM tools are ground within hours after having been removed from the transfer line. This puts incredible strain on the cutter grind department, which was used to grinding large batches of tools using a single set-up. Now tools arrive in the department in seemingly random fashion. Often lot sizes of tools are as small as two or three items per tool number (T#). This presented us with the need for a challenging process redesign which is detailed in Chapter Five.

The tools are ground in the CNC grinder without removing them from their holders. This required the development of special hardware for the machinery but provides benefits in efficiency and quality. Previously, job setters broke apart tools and holders, retaining the holders and passing the tools on to the retail crib. Thus, the tools were ground without the holders. When the tools were matched up with their holders after regrinding, the assembly process introduced run-out errors. Grinding tools in their holders eliminates these errors. The time required to dismantle tool-holder assemblies prior to regarding, and to put them back together again after the tools have been ground, was also eliminated. As with the wear measurement process, tools are ground one at a time, with care being taken to ensure that tools are returned to the proper tool tray slot after regrinding.

Tool Set-up & Build-up

Once the tools have been ground they are inspected for proper geometry, and proceed, in their tool trays, to the next step in the TTM process. Tools must be set to the appropriate height before they can be used again in the transfer line. During this step, each tool, identified by its position in the tool tray, is adjusted in its holder to provide the proper dimension during cutting. Tools which were marked by the cutter grind department as scrap (using red paint) are broken down and new a tool is mated with the tool holder.

Once the tool height has been set, the job setter divorces the tools from the tool trays and places the tools in a set of cabinets. The cabinets contain compartments for each spindle on the transfer-line. These compartments allow the cabinets to perform the same function as the tool trays. Segregating the tools in this manner throughout all parts of the tool flow means that a particular tool will be used exclusively in one spindle for its entire useful life. This provides us with a unique ability to track tool performance over time and across different spindles that use the same tool-number tools.

Once the job setter stores all of the reground tools he begins to set-up the tools needed for the next off-shift tool change. Using a list which has been provided to him, he loads the plastic trays with all of the tools that must be changed. These tools are taken from the aforementioned cabinets and have already been set to the proper height. The tools are then transported at the end of the first shift to the department's transfer line, and the process returns to point 'A' in Figure 4-3

Tool Inventories within TTM

Having discussed the flow of material, the system of tool storage bears mentioning. The tool flow creates a high material "velocity". After exiting the transfer line tools move rapidly from one processing step to the next until they are ready to re-enter the transfer line. But, often the amount of time it takes to prepare a tool for re-entry is significantly less than the tool change frequency. As a result, many tools will need to be stored between the Set-Up/Build Up step and their next tool change. Tools at this stage are stored in cabinets in the job setter crib. They are stored according to the spindle in which they are used and there is only room in the cabinets for one tool per spindle plus one additional tool per spindle for use in the event of an unscheduled tool change,

The only other storage location for tools is in the wholesale crib. These tools are not effectively in the TTM tool flow until they replace a scrapped tool presently in the flow. The wholesale crib tool inventories reflect the lead times to obtain tool shipments from vendors. No inventories are present in the machining department, and the retail crib inventories are eliminated in TTM. Reducing the number of tool storage locations from five to two leads to lower inventory levels by allowing variability in tool consumption to be averaged out by the grouped inventories.

Work-in-Process inventories are also greatly reduced. Under TEP's current tool management system the tools stored in the retail crib, and those in cutter grind, are effectively work-in-process. In TTM, work-in-process inventory turns over in less than 48 hours. Turn over of WIP in TEP's current system is in excess of two weeks for most tools.

Key elements of the Material Flow

When compared to the flow of tooling in the conventional tool management system described in Chapter Three TTM exhibits several key advantages. First, tools are identified on a spindle-by-spindle basis. This allows tooling performance to be evaluated as a function of each spindle in the machining department. Previously tools were evaluated on the basis of tool-number. This made it more difficult to identify problems that were specific to a particular spindle because tools which may have identified the spindle (or bushings, or fixturing) as faulty were mixed in with tools from other spindles which were operating properly. As a result, the correlation between tool condition and machine performance was poor. Under TTM this correlation is much stronger and more readily used to direct pre-emptive action.

Second, under TTM tools are prepared for their return to the transfer line more rapidly than in previous systems. By moving the tools rapidly through the clean-inspect-regrind-inspect-set process less inventory is required. Our goal in designing this tool flow was to prepare tools for re-entry into the transfer line within two days after their removal. This means that as long as tools remained in the transfer line for two days between changes we could operate TTM with only two tools per spindle. One would be used in the machine while the other was processed by TTM. Although additional tools would be required for emergencies, and to cover purchasing lead times, steady state operation would require only two sets of tools.

Third, a mechanism for feedback was established. By measuring each tool for wear and comparing the results of that measurement to the tool's expected tool change frequency, the tool change frequencies could be optimized on a spindle-by-spindle basis. This feedback mechanism provides a safeguard against both the over-running of tools and the premature removal of tools from the transfer line. Also, when tool wear is compared to a historical record for all tools used in that spindle a good indicator of possible machining problems results. If the tool wear is constant for a spindle over time, given a fixed tool change frequency, but then begins to rise, the condition of the tool, spindle, and machine tool warrants inspection. Likewise, if the amount of wear differs greatly for the same T# tools used in different spindles a production problem may be developing.

Finally, tool inventories are drastically reduced. Because of the rapid flow of tooling through TTM, only three sets of tools (two in the flow plus one emergency set) are required to supply the department's needs. All tool inventories are removed from the floor, and retail crib inventories are eliminated. Tools are only stored in two locations, the wholesale crib and the machining department's job setter crib. This allows TTM to achieve better control of tool consumption and to provide high quality tooling information for decision making. Figure 4-7 illustrates the overall flow of material and information under the TTM design.

Once we had laid out the above tool flow we needed to determine who would perform each of the above steps (some were obvious), and how information would be transmitted to workers and managers to coordinate tool flows and provide the information needed to monitor and improve tool performance. Decisions regarding the equipment required to facilitate the system also had to be made.

4.4 Information Flows within Trenton Tool Management

Information flows in TTM center around three activities: scheduling tool changes, monitoring tool performance, and the control of tool consumption and stockpiling. Figure 4-7 illustrates how information moves throughout the TTM system.

Scheduling Tool Changes

The heart of TTM is the tool change. Unlike a typical block tool change, in which tools are changed in predetermined groups at preset intervals, TTM creates tool change schedules dynamically. The process begins with a series of count sheets. A typical count sheet is shown in Figure 4-8. Entries are made on the count sheets for each spindle in the department. Each day the number of pieces made by each spindle is recorded and added to a running total. The daily part count is broken down by machining operation, where each spindle in an operation makes the same number of pieces unless an unscheduled tool change occurs. For each spindle, the running total of manufactured pieces is compared to the tool change frequency. When the running total approaches the tool change frequency the tool is added to the schedule for an upcoming tool change. Specifically, when the running total approaches the tool change frequency minus one day's average production, the tool is added to the tool change list for the upcoming evening. Once the tool is changed the running total is reset to zero.

For example, in Figure 4-8, the tool in operation 30R, station 10LH, spindle 407, has a tool change frequency of 2500 pieces, and as of August 25th its total piece count was 933 pieces. But, on the twenty-sixth this tool was found to be producing under-sized holes and had to be replaced. As a result its running total was reset to zero on that day. 30R-2LVA-404 on the other hand has a tool change frequency of 2500 pieces, and as of the 25th had a running total of 2253 pieces. So, to insure that the tool was not over-run it was changed on the evening of the twenty-fifth and its running total was reset on the 26th.

Trenton Tool Management System

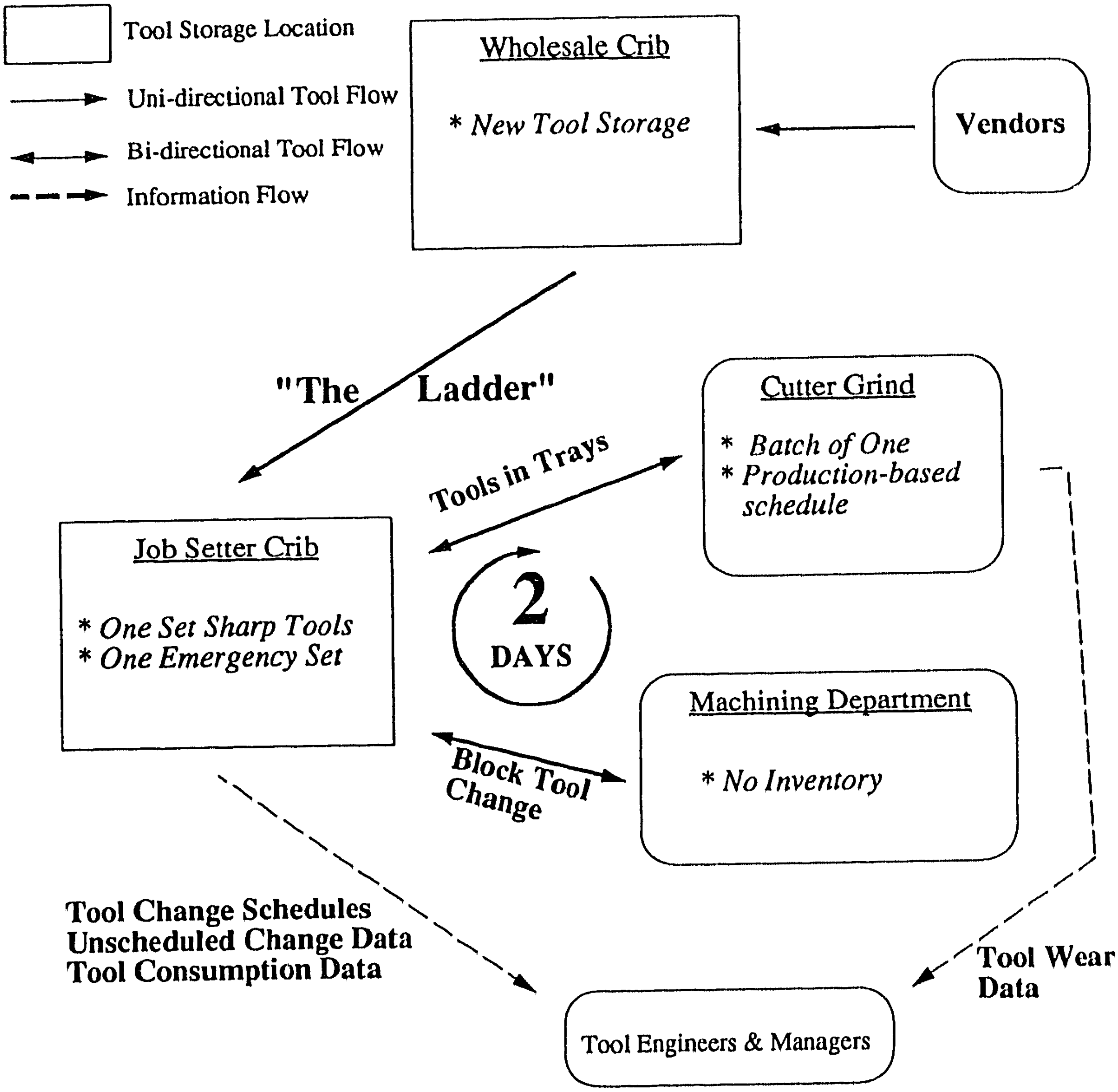
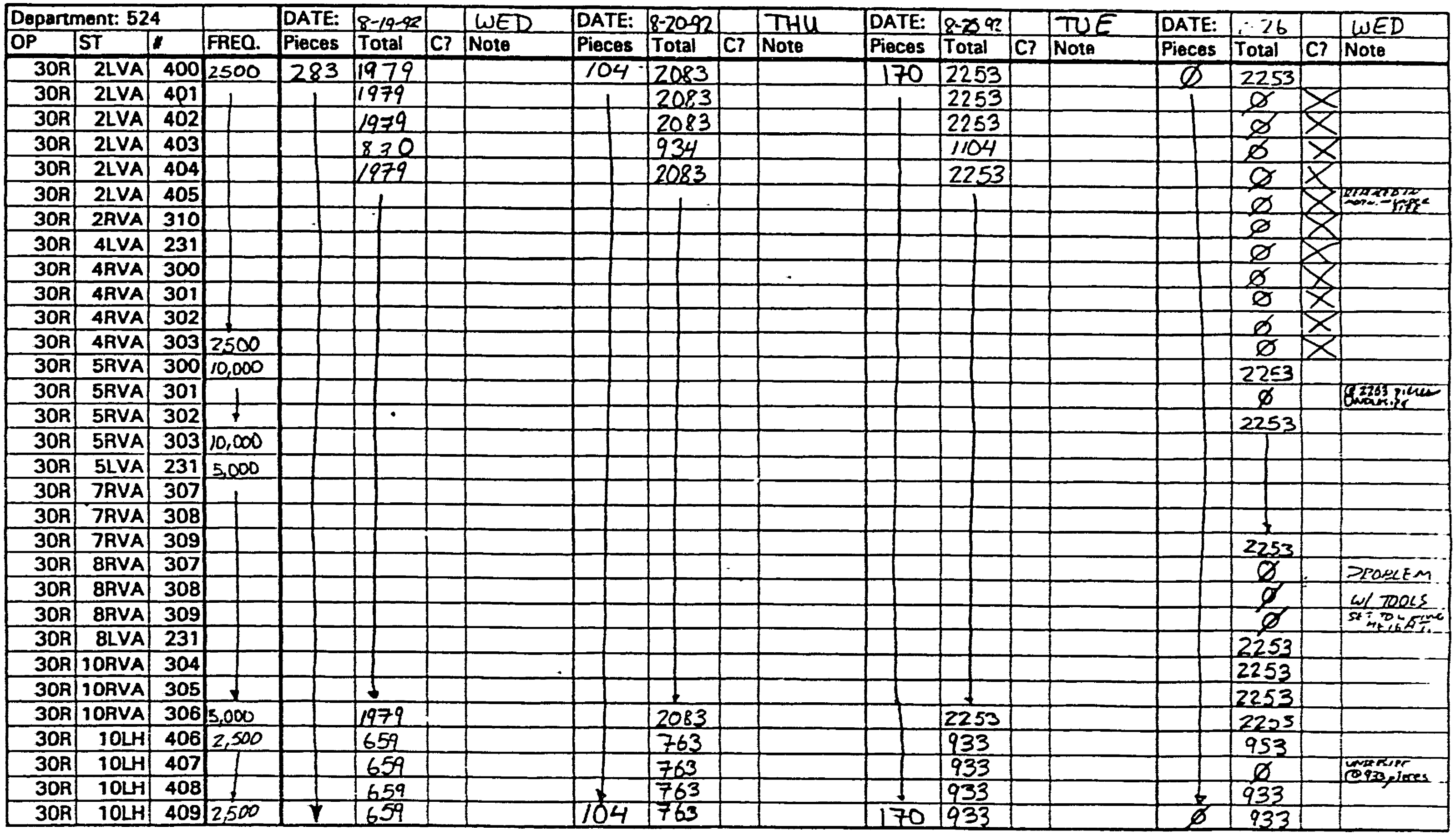


Figure 4-7: Trenton Tool Management provides a much simpler, and leaner, flow of tooling and information. The role of the retail crib as a storage location has been eliminated, and total tool inventories are substantially reduced. Under TTM tools can be prepared for use in the transfer line in less than two days compared to as long as one month in conventional systems.



Department: 524				DATE:	8-19-92		WED	DATE:	8-20-92		THU	DATE:	8-25-92		TUE	DATE:	..26		WED
OP	ST	#	FREQ.	Pieces	Total	C?	Note	Pieces	Total	C?	Note	Pieces	Total	C?	Note	Pieces	Total	C?	Note
30R	2LVA	400	2500	283	1979			104	2083			170	2253			0	2253		
30R	2LVA	401			1979				2083				2253				0	X	
30R	2LVA	402			1979				2083				2253				0	X	
30R	2LVA	403			830				934				1104				0	X	
30R	2LVA	404			1979				2083				2253				0	X	
30R	2LVA	405															0	X	[illegible]
30R	2RVA	310															0	X	
30R	4LVA	231															0	X	
30R	4RVA	300															0	X	
30R	4RVA	301															0	X	
30R	4RVA	302															0	X	
30R	4RVA	303	2500														0	X	
30R	5RVA	300	10,000														2253		
30R	5RVA	301															0		@2253 pieces [illegible]
30R	5RVA	302															2253		
30R	5RVA	303	10,000																
30R	5LVA	231	5,000																
30R	7RVA	307																	
30R	7RVA	308																	
30R	7RVA	309															2253		
30R	8RVA	307															0		PROBLEM
30R	8RVA	308															0		W/ TOOLS
30R	8RVA	309															0		SET TOOLING HEIGHT
30R	8LVA	231															2253		
30R	10RVA	304															2253		
30R	10RVA	305															2253		
30R	10RVA	306	5,000		1979				2083				2253				2253		
30R	10LH	406	2,500		659				763				933				953		
30R	10LH	407			659				763				933				0		[illegible] @933 pieces
30R	10LH	408			659				763				933				933		
30R	10LH	409	2,500		659			104	763			170	933			0	933		

Figure 4-8: Count sheet for operation 30 in the 3.5L cylinder head machining department (TTM pilot). Similar sheets are used for each operation in order to track the performance of all machining spindles.

Each day, the department's count sheets are reviewed to determine which tools need to be changed. A master change list is compiled and distributed to the department's job setter. The number of items on the change list is constrained by the number of tools that a job-setter can change per shift. As a result some tools are changed prior to their ideal tool change frequency to avoid over-loading the job setter, which would lead to the over-running of tools which he was unable to change.

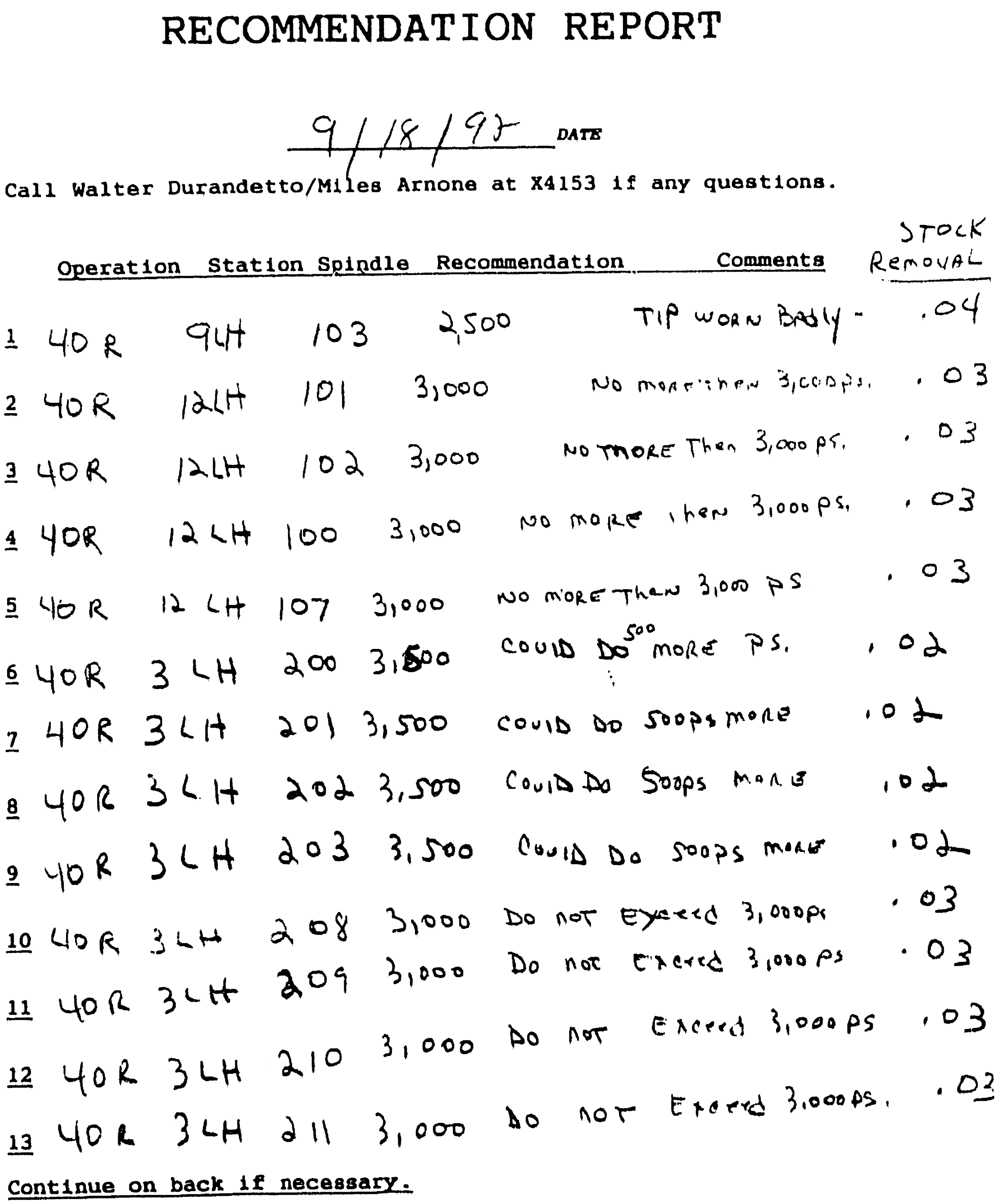
This list is distributed as early in the first shift as possible, to allow the job setter to pull the necessary tools from the cabinets and arrange them in the trays. Throughout the day, any tools which break unexpectedly are removed from the tool change list for that evening. The process of generating the tool change list, and keeping up the count sheets is performed manually by a tool engineer. For a line of 275 tools this requires approximately two hours per day. These activities are in the process of being computerized to free the tool engineer to perform other tasks.

The key feature of the tool change sheet generation process is that each tool is considered an independent entity. Tools are not necessarily changed at the same time because they are on the same station. In many cases, where unscheduled changes are minimal, they are changed together, but in cases where unscheduled changes are more common, the tools on a particular station are often changed one or two at a time. Treating tools as independent items for scheduling purposes allows each tool to be used for a greater proportion of its tool change frequency than if the tools were grouped into blocks. It also reduces the total number of tool changes required over a given time period. The penalty of treating each tool independently is reduced economies in the grinding and handling of tools afforded by large batch sizes.

Monitoring Tool Performance

The second role of information within TTM is to monitor, evaluate, and improve tool performance. Tool monitoring is made possible by linking tools to specific spindles in the transfer line, and by the feedback mechanism created by the wear measurement process.

Each tool removed from the transfer line as part of a scheduled tool change is inspected for wear. A record is then made indicating whether this tool was left in the transfer line too long, or whether it could have been left in for longer periods of time. These evaluations are recorded on a "recommendation sheet", shown in Figure 4-9.



RECOMMENDATION REPORT

9/18/92 DATE

Call Walter Durandetto/Miles Arnone at X4153 if any questions.

	Operation	Station	Spindle	Recommendation	Comments	STOCK REMOVAL
1	40R	9LH	103	2,500	TIP WORN BADLY -	.04
2	40R	12LH	101	3,000	NO MORE THEN 3,000 PS.	.03
3	40R	12LH	102	3,000	NO MORE Then 3,000 PS.	.03
4	40R	12 LH	100	3,000	NO MORE then 3,000 PS.	.03
5	40R	12 LH	107	3,000	NO MORE THEN 3,000 PS	.03
6	40R	3 LH	200	3,500	COULD DO 500 MORE PS.	.02
7	40R	3 LH	201	3,500	COULD DO 500PS MORE	.02
8	40R	3 LH	202	3,500	COULD DO 500PS MORE	.02
9	40R	3 LH	203	3,500	COULD DO 500PS MORE	.02
10	40R	3LH	208	3,000	DO NOT EXCEED 3,000PS	.03
11	40R	3LH	209	3,000	DO NOT EXCEED 3,000 PS	.03
12	40R	3LH	210	3,000	DO NOT EXCEED 3,000 PS	.03
13	40R	3LH	211	3,000	DO NOT EXCEED 3,000 PS.	.03

Continue on back if necessary.

Figure 4-9: Recommendation sheet from September 18, 1992. Each tool received by cutter grind is evaluated for wear, and a recommendation is made as to whether the tool's change frequency should be increased, decreased, or left the same. For the seventh tool on the list, OP40R-ST3LH-#201, the cutter grinder recommended that the tool change frequency be increased from 3,000 to 3,500 pieces.

At the beginning of first shift the worker inspecting the tools receives a copy of the previous evening's count sheet. In addition to listing those tools which were changed, the tool change frequency for each tool, and the number of pieces made by the tool, are provided. Using this information, and by measuring the amount of tool wear, the worker recommends changes to the tool life frequency. These recommendations are then forwarded to the tool engineering department for approval. Those recommendations that are approved (the overwhelming majority of recommendations are approved) lead to changes in the tool change frequency appearing on the count sheet. Looking at Figure 4-9 we see that the cutter grinder made a series of recommendations for each tool he received. In some cases he recommended that the tool life be increased, while in other cases he felt that the tool life should be held at its present value.

Compiling historical data on tool wear vs. pieces manufactured provides a powerful tool for evaluating tool performance. When a new tool number (T#) tool is first used in a department, its tool life is usually established by rule of thumb, and tends to be conservative. So, initially, as a tool flows through the TTM system the worker evaluating wear is likely to recommend that its tool life increase. Eventually, the tool life will stabilize, probably with some oscillation around its steady state value due to measuring error, and variations in transfer line performance. Thus, after several tool changes the tools used in a particular spindle will have a well established tool life. Figure 4-10 illustrates a typical pattern of tool life increase for one of the tools used in the pilot department.

Once a steady state tool life is obtained we have a reference for identifying aberrations in tool performance, and for evaluating the impact of changes in tool design and operating procedure. If for example, a tool has a steady state tool life of 5,000 pieces we would expect that a worker evaluating the tools after they had run for 5,000 pieces would recommend no change in the tool change frequency. But, if a recommendation is made to cut 1,000 pieces from the tool life, after weeks of running for 5,000 pieces, a problem has been flagged. The cause of the problem may be the machine, the workpiece, the quality of the regrind, or the tool's original geometry. While the recommendation doesn't give us any insight into the cause of the problem it does indicate that the situation warrants investigation. Note that this "flag" goes up before tools are broken. It allows us to pro-actively address operational problems in the transfer line, instead of waiting to fire-fight these problems when they bloom into disasters.

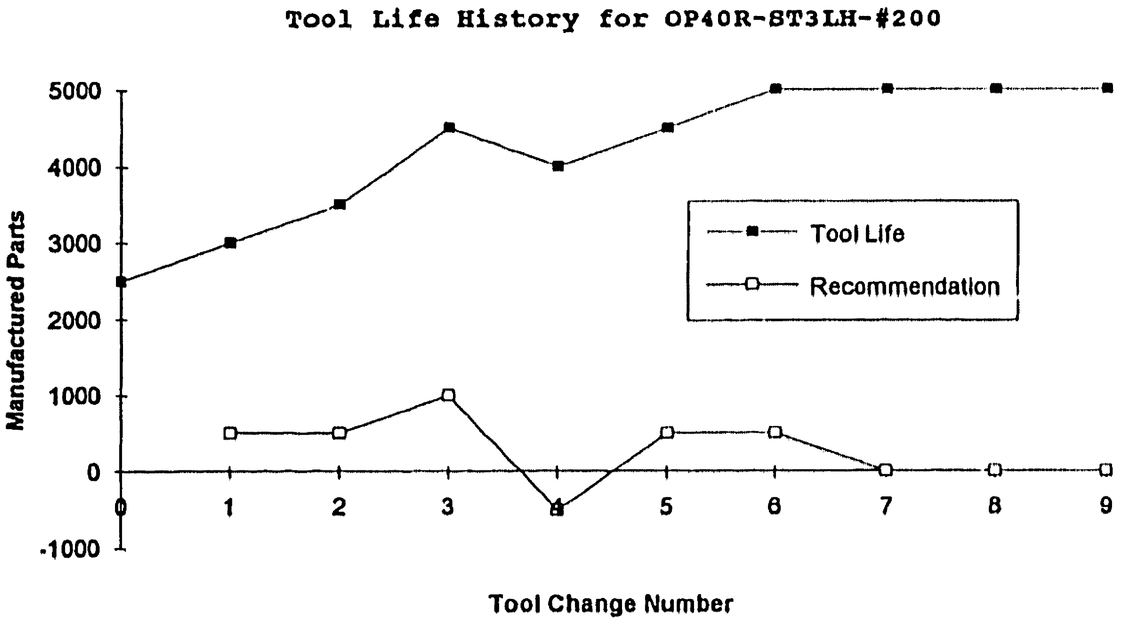


Figure 4-10: History of tool change frequency and recommendations for OP40R-ST3LH-#200. Note that the initial tool change frequency estimate of 2500 pieces was conservative, and that the tool life eventually stabilized at 5000 pieces after six tool changes. Once the tool life is stable recommendations to alter the tool change frequency "flag" possible changes in the machining process.

During the pilot operation this feature successfully identified numerous problems before they grew out of control, and allowed tool life on the 3.5L head line to exceed predicted values by a ratio of 2.6:1.[13] Several examples are presented in Chapter Six.

Tool wear information can also be used to evaluate new tools scientifically, and improve the cost effectiveness of the tooling in use. If a tool engineer is unsatisfied with the tool life of a particular tool, he can introduce a test tool into TTM on one or more spindles and monitor the tool life of that tool through the recommendation sheets. Once the steady state tool life of the new tool is established, the tool engineer can use this information, along with tool cost, breakage, and regrind information, to determine which tool provides the best performance. At present, to evaluate a new tool, a tool engineer performs a tool test. The tool engineer depends upon the machine operator to keep a running log of the tool's operation until the tool is removed. These logs are often ignored by the operators, or inaccurately maintained. As a result, it is difficult for tool engineers to obtain accurate information about a test tool's performance. In addition, the engineer often has little information about the old tool's performance. He may only have a rough estimate for the old tool's change frequency. Data regarding the breakage history of tools, and the number of times a tool can be reground is not available.

The count sheets provide the tool engineer with additional information regarding tool performance in the form of unscheduled tool change data. Each time a tool is removed from the transfer line before it is scheduled to be changed (e.g. - because of breakage, excessive wear) a record is made in the count sheet. This information, which is obtained as part of TTM's control functions, details when an unscheduled tool change occurs, and the nature of that tool failure.

In its ultimate form, TTM allows the tool engineer to rank the performance of tools in the machining department on a spindle-by-spindle basis. This is done by establishing a cost-per-part for a given spindle. The cost-per-part measure is calculated using information from the count sheet and recommendation sheet. Costs included are the purchase cost of tools, the inventory carrying cost of the tools on hand for the spindle in question, the number of tools consumed on the spindle, and the number of regrinds and the cost per regrind. These costs, evaluated over a suitable time frame (generally one month) relative

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[13] Interview with Walter Durandetto, Chrysler Corporation, Trenton, Michigan, 4 May 1993.

to the life of a single tool from purchase to scrap, are divided by the number of parts manufactured by the machining department over this time.

The cost-per-part allows tool engineers to determine the true high-cost items in the department, and prioritize their tool improvement efforts to maximize returns to the plant. It also can be used to identify trends for a particular spindle, or for a single T#. Changes in cost-per-part data are valuable because they alert tool engineers to the degradation of tool performance, in which case it may prove worthwhile to contact vendors for possible replacement tools, particularly if the tool has a high cost-per-part. This data can also be shared with vendors as a means of providing them with quantifiable targets for new tools. If a vendor knows the level of performance that a tool must provide he can more rationally design or price that tool to provide a competitive solution to the plant. Such a rationalization of tool purchasing would also eliminate much of the nepotism, which takes the form of lunches, golf outings and other perks provided to engineers by vendors, that surrounds the process. Nepotism exists because no measures are in place to objectively measure the performance of a particular tool. So, while very good, or very bad, tools, are easily identified, it is difficult to evaluate the performance of the vast majority of tools. As a result, "service" to the tool purchasing agents and tool engineers, rather than to the plant, becomes the basis of vendor evaluations.

TTM Control Functions

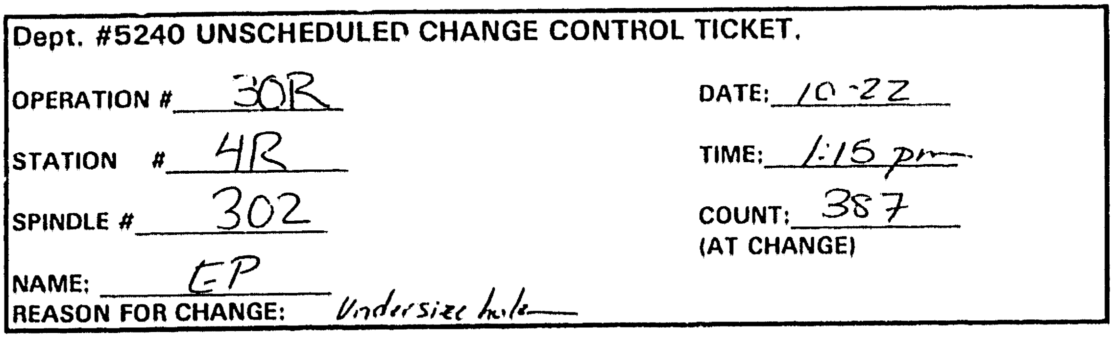
In order to have high quality information regarding tool performance, and to restrict inventories, controls need to be placed upon the consumption, and storage of tools. As described in Chapter Four, the goal of TTM is to operate the entire department with only two sets of tools. Additional tools, to cover purchasing lead times, reside in the wholesale crib and are effectively off-limits.

Our discussion up to this point has taken on a somewha idyllic view of the world and TTM's role in it. It has not addressed several key problems that currently plague TEP. In analyzing the TTM tool flow two questions arise: How does TTM monitor and respond to unscheduled tool changes? And, how does TTM eliminate "Underground Economy" activities? Effectively addressing these two issues is the key to TTM's success. If TTM can not effectively respond to unscheduled tool changes, and remove incentives for machining departments to pursue underground activities, tool inventories will grow and the system will once again be out of control.

It is particularly critical that TTM provide a rapid response to unscheduled tool changes because within TTM there are no tool inventories on the floor of the machining department. As a result, operators can not replace tools on their own. The benefit of preventing operators from putting on-hand tools into the line is that bad tools are less likely to end up in the line, and large numbers of tools can not be consumed in a short period of time without notifying other plant personnel. TTM provides a link between the operators and the job setter in order to minimize the time required to perform an unscheduled tool change. This link takes the form of an unscheduled tool change ticket, and a small inventory of "emergency" tools under control of the job setter at a location distant from the machining department.

When the operator identifies an unscheduled tool change he fills out an unscheduled tool change ticket [Figure 4-11]. Filling out this ticket forces him to provide adequate information for TTM to catalog the occurrence, and allows the job setter to bring the proper tool to the line for the tool change. Once the form is filled out, the operator alerts his supervisor, who in turn contacts the job setter by radio or telephone, identifying the unscheduled tool change by the operation, station, and spindle at which it occurred. In Figure 4-11 the tool in question is OP30R-ST4R-#302. The interaction between the operator and his supervisor is an important element of the control function because it ensures that the supervisor is made aware of the tooling condition. In past practice operators could change many tools in succession without interacting with the supervisor. While in most cases the supervisor acts only as an intermediary between the operator and job setter, it is important that he be made aware of the activities in his line because his performance is reflected by the consumption of tooling in the department.

Once the job setter has been called, he brings the appropriate emergency tool to the department and changes it. The job setter crib contains one emergency tool for each spindle in the department. These tools are set-up like the other tools and reside in specially marked compartments in the tool storage cabinets. Emergency tools do not regularly flow through the TTM system until they replace a scrapped tool. Once the emergency tool replaces a scrapped tool it moves through TTM like the other tools. A set of emergency tools is kept in the job setter crib to allow him to respond rapidly to unscheduled tool changes, which cause down-time in the machining department. By keeping the emergency tools assembled in their holders, and set to the proper heights, the job setter can select the tool,



Dept. #5240 UNSCHEDULED CHANGE CONTROL TICKET.

OPERATION # 30R

STATION # 4R

SPINDLE # 302

NAME: EP

REASON FOR CHANGE: Undersize hole

DATE: 10-22

TIME: 1:15 pm

COUNT: 387
(AT CHANGE)

Figure 4-11: Unscheduled tool change ticket from TTM pilot. Operators fill out these tickets to identify the exact location and time of an unscheduled tool change.

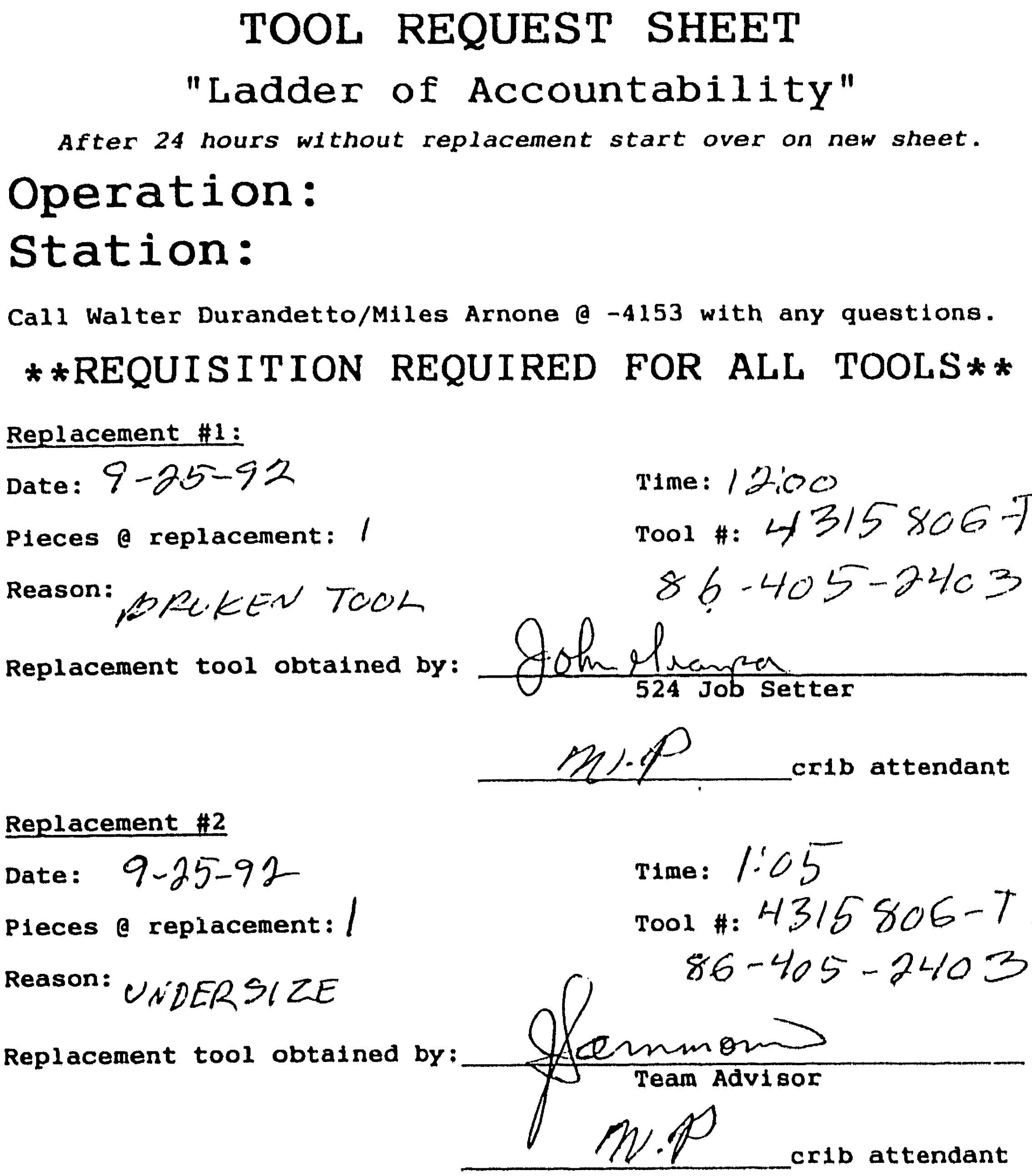
travel to the line, and install the new tool in about the same amount of time that an operator on the line could have responded to the unscheduled tool change using local inventories.

After the job setter changes the tool, he takes the ticket from the operator and returns to the crib. This ticket is then used to alter tool change schedules as appropriate, and is used to create a record of the event on the count sheet. The job setter then goes to the wholesale crib to obtain a replacement tool for the emergency tool which he brought to the department. A tool is issued, and an entry is made in "The Ladder".[Figure 4-12]

The purpose of the ladder is to prevent successive tool changes from occurring on a given spindle over a short period of time without the managers form the department being made aware of the high levels of tool consumption. If the unscheduled tool change was the first to occur on that station within twenty-four hours, an initial entry is made in the ladder. This entry indicates the time of the tool exchange and is signed by the job setter. If the tool must be replaced in the transfer line again within twenty-four hours the job setter can bring a replacement to the department because he restocked his emergency inventory after the first unscheduled tool change. But, now when he approaches the wholesale crib for a new emergency tool it will not be issued to him unless the department supervisor comes to the wholesale crib to sign for the tool. Figure 4-12, which shows a second tool signed for by the supervisor, reflects this situation. This ensures that the supervisor has been made aware of the condition on the station in question. He can then choose to keep feeding the line tools, and/or can take corrective action.

This process continues, moving up the rungs of the Ladder until the department manager (area manager) has to sign for the tools. If the area manager wants to continue consuming tools after the fifth unscheduled change within twenty-four hours he can do so, but notice is sent to TEP's production manager and plant manager.

The goal of the Ladder is to motivate managers to make a conscious decision as to whether the department should continue to consume tools, or should stop the line for maintenance. Under TEP's current tool management system managers often don't have the option to make this decision because operators run through a large number of tools before managers are made aware of the problem. By the time they do learn of the condition the plant may have run out of tools and shutting down the line becomes a necessity rather than an option.



TOOL REQUEST SHEET

"Ladder of Accountability"

After 24 hours without replacement start over on new sheet.

Operation:

Station:

Call Walter Durandetto/Miles Arnone @ -4153 with any questions.

****REQUISITION REQUIRED FOR ALL TOOLS****

Replacement #1:

Date: 9-25-92 Time: 12:00

Pieces @ replacement: 1 Tool #: 4315806-T7

Reason: BROKEN TOOL 86-405-2403

Replacement tool obtained by: John 524 Job Setter

M.P crib attendant

Replacement #2

Date: 9-25-92 Time: 1:05

Pieces @ replacement: 1 Tool #: 4315806-T7

Reason: UNDERSIZE 86-405-2403

Replacement tool obtained by: Team Advisor

M.P crib attendant

Figure 4-12: Example sheet from "The Ladder". This control mechanism was designed to prevent high levels of tool consumption without managerial awareness. In this example, the TTM pilot department supervisor has signed for a second tool, and has therefore been made aware of what may develop into a machining problem.

While most aspects of TTM treat each tool as an independent entity, the Ladder looks at the department on a station-by-station basis. This is necessary because many stations use the same tool number (T#) tools in several spindles. As a result, emergency tools could be swapped between spindles, thwarting the Ladder's notification mechanism.

The Ladder is the primary mechanism for preventing excessive tool consumption, and for preventing the accumulation of floor inventories. Additional mechanisms were established to prevent tools from entering the machining department through "underground" activities. New controls were established to prevent tools that failed inspection (DM), and those that have not yet been inspected (TBI), from leaving the shipping area. Secured cribs were built to hold the material, and crib personnel were empowered to refuse to distribute DM and TBI material without high-level approval. These procedures, which were developed under the direction of the crib staff, have proven effective at preventing poor quality tools from entering production and creating scrap material and bloated inventories. Appendix B presents the document outlining the policy we developed.

The DM/TBI procedures we developed are critical elements of TTM because without them we do not posses control of all the tooling inventories. Without this control the quality of tools can not be ensured, and tool-related information is not reliable. If tools enter the machining department unbeknownst to TTM then it becomes impossible to advise the tool engineers and managers in such a way as to bring about improved performance. Combined, the Ladder and the DM/TBI policy provide internal and external control over the tool inventories used in a machining department. These systems serve as the foundation of all other aspects of TTM by creating an environment of certainty regarding material and information related to the tooling used at TEP.

4.5 Physical Components of TTM

We designed, and purchased, equipment to facilitate the flow of material and information through TTM. Much of this equipment, like the trays and cabinets, served as visual controls, making it possible to monitor tool inventories, and the condition of the tooling. Other equipment was needed to facilitate the inspection and regrinding of tools in an economical and rapid fashion. Some of the more significant items are discussed below.

Tool Trays

Working with Uniflex, Inc., of Wixom, MI, we designed a series of plastic trays for tool handling. Two full sets of trays are used as part of TTM, and each set is capable of holding one tool for every spindle in the pilot department, the 3.5L cylinder head line. A typical tray is shown in Figure 4-13. A total of twelve different tray geometries were required to accommodate all of the different tool geometries in the pilot department. All of the trays for a single department share a common color so that for regrinding and inspection purposes each department's tools can be distinguished from one another. The trays are divided into several compartments so that each tool can be segregated from other tools in the same tray. This prevents the tools from being damaged and makes it possible to distinguish the tools by the spindle in which they are used. Each compartment is labeled with the operation, station, and spindle number of the tool that will be placed there. To make tracking and handling of tools and trays easier, only tools for one station are placed in the same tray. This prevents a tray from containing tools for multiple stations, which may be far apart in the transfer line, and makes the trays more valuable as a means for the second shift job setter to organize his tool changes.

The trays are also designed to withstand the high temperatures of the tool washer, and have a perforated bottom which allows the tools and trays to be placed directly into the washer without interfering with the cleaning process. The ability to wash the tools without separating them from the trays is important because tools are identified by their place in the tray.

The main reason for employing these trays is to facilitate the off-shift tool change. In typical block tool change systems, large carts with designated slots for each tool, or unmarked trays, are used to move tools between the job setter crib and the transfer line. We felt that for TTM's dynamic tool change these were sub-optimal designs. First, these methods of tool transport make it difficult to ensure that as a tool is removed from a spindle it is swapped with the correct new tool, and then placed in the appropriate location to identify it for wear measurement and regrinding. When using a cart, job setters tend to gather up a bunch of tools at a time and bring them to the machining station, rather than shuttling the tools one at a time from the cart to the head. This is done because it is impossible to bring the cart close to the head, and because changing the tools often means climbing up or into a machine. It is easier, and faster, to change the tools if they are all brought to the station head at once. The problem with this approach is

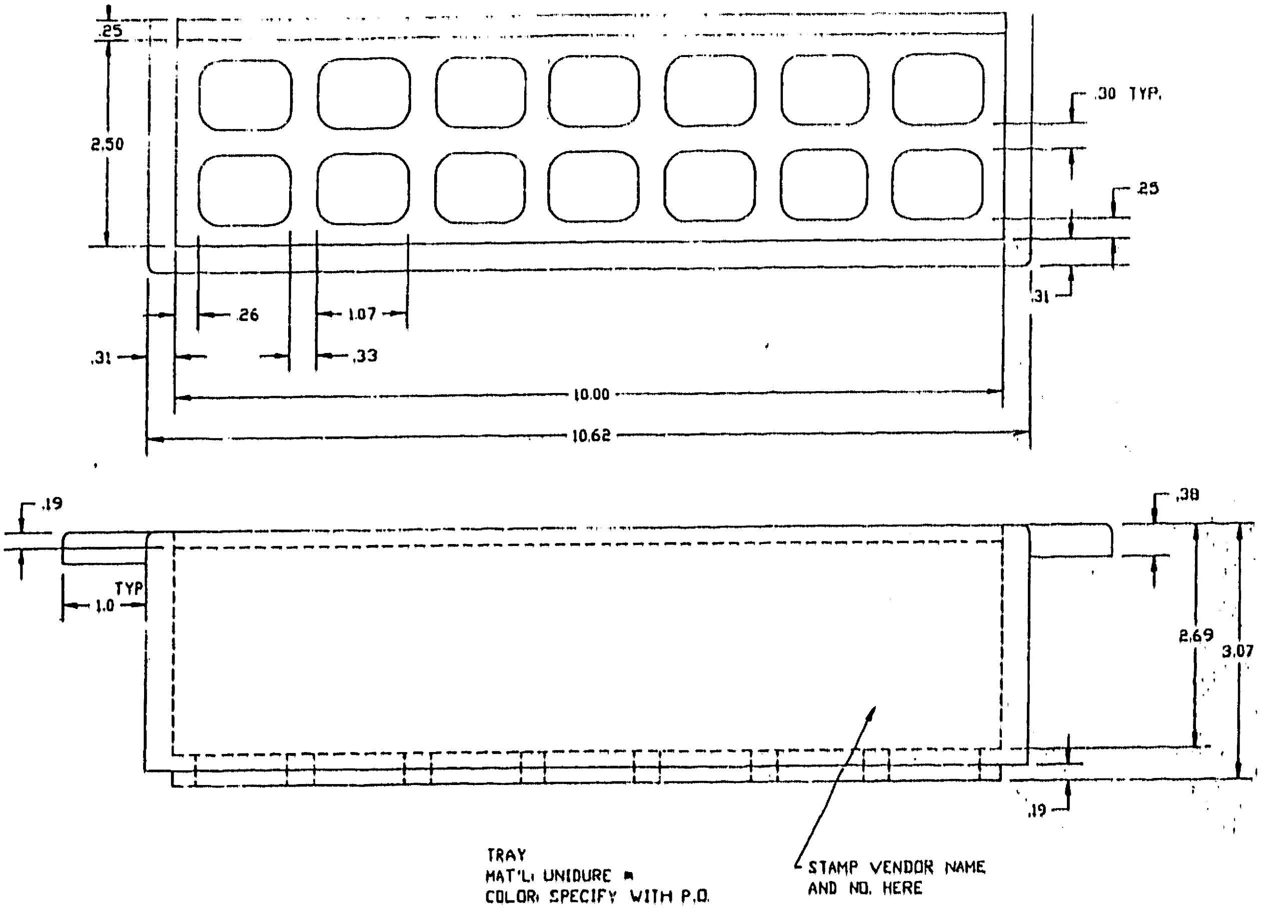


Figure 4-13: Print for one of the tool trays designed for use in Trenton Tool Management showing a complete side view, and a partial top view, showing one compartment. Note the handles and the holes to allow the passage of water during washing. The trays are manufactured by Uniflex of Wixom, Michigan, and are made of a lightweight but durable plastic which can withstand the high temperatures of a part washer.

that often the tools are gathered up in the job setter's arms and then put down on the machine bed. From there they can fall on the floor or get chipped.

The TTM tool tray design makes it easy for the job setter to swap new and worn tools one at a time between the spindle and the tray. While it can not guarantee that this is done, it removes many of the incentives for not changing tools in this manner. Also, the trays were designed to be light enough to be carried between a cart, used by the job setter to push the trays from operation to operation, and the machining heads. The tray can be placed on top of the machining head without risking damage to the tools or machine.

Finally, the trays serve as a means of organizing, and checking the tool change. At the beginning of the off-shift the job setter picks up the trays from a central location in the machining department. Typically, he will collect all of the trays for one operation, and then will change those tools, followed by the next operation and so on. Because the trays are labeled, the job setter can readily identify which operations, stations and spindles require a tool change.

Tool Storage Cabinets

In order to store the limited tool inventories under TTM we set-up a series of cabinets which act much like the tool trays, except that they are stationary. Like the trays, the cabinets are designed to segregate each tool on the basis of where it is used on the transfer line. For each spindle there are two storage spaces in the cabinets. One is for the tool which has been reground and is waiting to be used in the transfer line, and the other space is for storing the emergency tool for that spindle. The different storage spaces are indicated using labels which identify the operation-station-spindle for the tool in question. A red label identifies the emergency tool and a black label identifies the tool which is a part of the TTM flow. The cabinets are arranged so that the tools are ordered as in the transfer line. The first drawer of the first cabinet begins with the first tool to machine a workpiece in a line and continues through each operation until the last tool in the last operation is reached.

Other than the arrangement of dividers within each drawer, these cabinets are standard tool storage cabinets. The key feature of the cabinets is that there is space for only two tools for each spindle in the line. There is nowhere to store additional tool inventories in the job setter crib. If tools are stacked in other locations it is an indication that inventory has grown beyond that amount dictated by the design of TTM. In conventional tool management systems such visual controls for inventory do not exist, and so it is difficult to determine if inventory is higher than desirable without an in-depth study.

Specialized grinding collets

When tools are reground under TTM we do not wish to disassemble them from their holders, as is the common practice at TEP. By eliminating disassembly we reduce redundant activities (e.g. - disassembly followed by reassembly) and the potential for errors. Grinding the tools in their holders also ensures a higher degree of concentricity between the tool, its holder, and ultimately the spindle. Grinding the tools in the holders presented a problem because all of the holders are built with keys. These keys mate with a slot in the spindle and prevent the tool from slipping relative to the spindle under high loads. Removing the key requires the application of force to the holder and destroys the key. While the keys are inexpensive, this process can damage the holder, and results in additional labor.

Our solution was to design special collets, which had a key-way ground in them, for use on the CNC grinder. These collets, which were detailed and manufactured by Kennametal, allow tool assemblies to be taken from the tool trays and placed directly into the grinder. Because of the need to maintain a high degree of concentricity between the ID and OD of the collet, we were unable to use existing collets and modify them through the addition of a key-way. Instead the collets had to be made from blank stock, the key way added, and the fillet pattern modified to accommodate the key way. Figure 4-14 shows a blueprint for one of the four collets that were manufactured by Kennametal. Only four collets were needed because of the standardization of holder diameters used in the machining departments. Before we began grinding tools in their holders over twenty different collets were required.

Video Inspection Gauge

In order to quantify the amount of wear on a tool, a fairly precise measuring instrument is required. At the same time, an instrument that would allow workers to identify subtle wear characteristics was desired. These features are often less than 0.001" in size, and so using hand-held measuring devices like calipers or micrometers is not acceptable. Present practice in the cutter grind department regarding tool inspection was not acceptable, and it was widely agreed that improved equipment was necessary, and that such equipment might foster a sense of ownership among the cutter grinders, and therefore greater

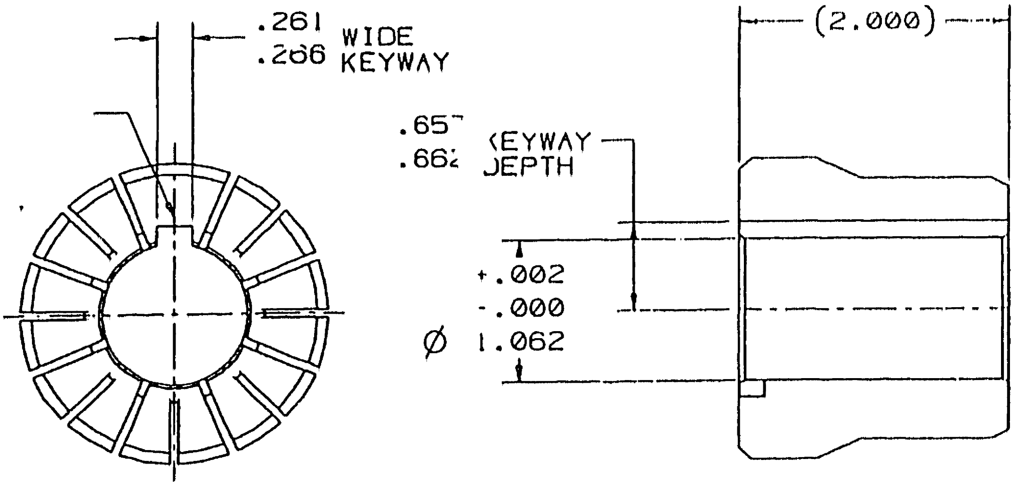


Figure 4-14: Design of special 1.062" collet for use on CNC grinding machine. This collet, along with three others for different size tool holders, allows tools to be ground without disassembling the tool assembly.

productivity. This indeed had been the case when the CNC grinders were installed several years ago.

We specified a video based gauge from RAM Optical for use in measuring the wear on tools, and for inspecting ground tools. The system is controlled by a menu driven PC, and can be programmed to automate tool inspection based on tool number. The gauge magnifies an image of the tool tip and then the operator manipulates a cross-hair on a video screen to identify particular features. The gauge then calculates the distance between identified features and compares these measurements to stored values. Complex features, such as curves, in addition to simple distances, can also be inspected. The system also uses a video printer to provide high magnification (250X) images. When used by tool engineers these pictures provide a valuable diagnostic tool for evaluating tool failures, as well as the quality of new and reground tools.

The video gauge was chosen over more conventional optical gauges because it is capable of handling a larger volume of tools, and can create a permanent record of tool measurements. It can also compare a measured tool to a previously established master which is stored inside the gauge's PC. Also, the video gauge provides the ability to share information between the plant and vendors, via the video printer. Finally, because the gauge is PC driven it provides a means of automatically integrating tool wear information into a PC-based TTM information system.

TTM Information System

While the information flows described above are paper-based, our ultimate goal is to construct an information system which will semi-automatically generate tool change schedules, and track tool performance. The system would embody all of the functions performed manually to maintain the count sheets, while providing a user-friendly interface which would provide managers, engineers, and hourly workers with information regarding the five performance measures described in Chapter 3, and the more specific information generated by the tool performance monitoring features of TTM.

While this system has not yet been implemented, extensive work has been carried out with Royal Design and Manufacturing to modify their existing tool management software into a form which better meets TEP's needs. The changes primarily center around the user-interface and the manipulation of collected data into measures which are more meaningful to TTM's constituents.

The goal of the TTM I/S is to automate many of the calculations required to create tool change schedules, and to aid in the identification of troublesome tools. It will do this by internalizing the procedures which are presently carried out manually (e.g. - adding pieces on the count sheets), and presents them through a well-defined object-oriented interface to TTM's constituents. A central server is used to link together PCs in cutter grind, the job setter crib and tool engineering. This system, with a basic form of the software, is scheduled to be installed in May 1993. Eventually, as TTM grows throughout TEP this system will be made an integral part of a plant-wide information system.

4.6 Allocating Human Resources in Trenton Tool Management

Once the tool and information flows had been defined the next task was to determine who would perform each task. This was done by evaluating the time required to perform each of the functions defined in the tool flow. The cycle times for each step were mated with information regarding the volume of tools that would be handled by the pilot, and available man-power. Several simulations were run and work was allocated among available personnel in an attempt to balance the work load for each person in the tool flow.

Our attempts to balance the work load were complicated by the UAW leadership, who were concerned about the impact of redefining workers' roles from traditional activities. These concerns stemmed primarily from their belief that instituting a tool management system would eliminate jobs. During the development of TTM we did not strive to reduce man-power. Rather, we worked to improve overall performance of the plant as defined by improved cost and product quality. But, the tool flow, as defined above, did effectively eliminate the role of the retail crib personnel. This was brought to our attention by the UAW Committeeman responsible for that portion of the plant. As a result, the man-power allocation was modified so that retail crib personnel would deliver the sharp tools to the department prior to each block tool change, and return the worn tools after the change. This represented an optimal result because it met the UAW's needs to provide the retail crib personnel with work in TTM which was analogous to their current functions, and because it allowed the job setters to spend more of their time preparing and changing tools.

Our general approach in defining the role of each group of workers was to give them a stake in the decision making processes of TTM, rather than having them act as transfer mechanisms, moving tools from one process to another. In this way we hoped to harness the expertise that these workers possessed regarding tooling, and machine tool performance. Each group of workers has a large amount of responsibility within TTM, and their actions can directly improve or disable the system. This approach differs from typical tool management approaches which strive to eliminate the ability of workers to interfere with system performance, and in doing so also eliminate their ability to contribute positively to its development. Unfortunately for these other approaches, it is easy to restrict the ability of workers to improve a system and nearly impossible to prevent them from hindering it.

The following descriptions outline the role of TEP employees within TTM.

Job Setters

For the pilot department, two job setters were available. One of these was assigned to the second shift to change tools. The other job setter was assigned to the first shift. His tasks are to wash tools prior to grinding, and then to set-up and organize the tools after they have been ground. In addition, this job-setter, who is on duty while the transfer-line operated, handles unscheduled tool changes (breakage) that occur. These tasks fell under the conventional job description for a job setter. Under TTM, job setters perform the same work, only arranged differently.

Under TTM job setters also perform the important role of overseeing the department's tool inventories. It is in large part up to the job setter to see to it that discipline regarding tool inventories is maintained and that carrying costs are minimized. Because he sets up each tool before it re-enters the transfer line, the job setter is also in a good position to provide feedback to cutter grind regarding the quality of its work, and to work with that department to address tooling problems that can be corrected by alterations in the grinding process.

Cutter Grinders

The cutter grind department is responsible for inspecting incoming tools for wear, grinding the tools, and inspecting them again for proper dimensions. These are tasks performed by the department under the current tool management system. But, again, TTM reorganizes the manner in which these tasks are performed.

Based on our simulations, the cutter grind department represented the bottleneck for obtaining rapid tool flow. In particular, the CNC grinding process limited the rate at which tools could be removed from the transfer line and reprocessed. As a result we worked closely with this department to redesign the manner in which tools were reground, and to promote interaction with the job setter to improve flow through cutter grind.

The cutter grind department is in a critical position regarding TTM. As the cutter grinders are experts regarding tool performance they are well positioned to identify tooling problems and work with tool engineers to correct them. This is because they handle all tools after they are removed from the transfer line and before they are reground. After the tools are reground any information they contain regarding the effectiveness of the machining operation is lost. So, it is important that cutter grinders be empowered to critically evaluate the condition of tooling and be able to work with tool engineers to rectify deficiencies.

Retail and Wholesale Crib Personnel

As mentioned above, the involvement of the retail crib personnel came as a direct result of UAW intervention. This turned out to be a significant positive event because the retail crib personnel, particularly the TC, Joe Martin, contributed greatly to the success of the pilot program. Under TTM, retail crib personnel no longer handle each tool after it is removed from the transfer line. Instead, they use a flatbed cart to transport batches of tools in trays to the machining department for each off-shift tool change. They then pick up worn tools from the department at the end of the tool change.

Personnel from this department also interacted with the job setter when he needs to obtain new tools. As a result, they maintain the Ladder and regulate the flow of new tools to the department. The staff of the crib was also instrumental in developing the DM/TBI policy and is responsible for carrying out the procedures it describes.

Tool Engineers

The role of the tool engineer in TTM is to create tool change schedules and monitor tool performance. Working closely with the job setters and cutter grinders he identifies problem areas and works to improve tool performance while reducing cost. Once the tool change scheduling becomes more automated his time will be spent exclusively on improving the performance of the machining department's tooling.

The tool engineer is effectively the administrator of the TTM system. He acts as the interface between the various groups of workers in the system, and generates system improvements as TTM evolves. In addition, tool engineers represent TEP's principal means of interacting with tool vendors, and tool engineers have a lot of influence regarding which tools are purchased.

While the role of tool engineers within TTM is to generate process improvements, at present TEP's tool engineers spend most of their time performing other tasks, many of which are clerical. With the large amount of down sizing at Chrysler, tool engineers are needed to chase purchase orders, modify blueprints, and expedite tooling through cutter grind and to the machining department.

5.0 3.5L Head Line Pilot Implementation

This chapter discusses the implementation of the Trenton Tool Management System on the 3.5L head line at TEP. This department was chosen for the pilot primarily because its manager, Larry Deszell, had experience with block tool changes and was anxious to adopt some form of tool management for the department. Larry played an instrumental role in designing TTM, and implementing the pilot. His need for information about tooling performance, and his desire to avoid high levels of tool consumption, motivated many of the elements of TTM described in Chapter Four.

The decision to pilot TTM on the 3.5L head line was also influenced by factors other than the commitment of that department's management to the concept. As a new machining department, TTM would be implemented as the first parts were rolling off the transfer line. This made it easier to control tool inventories and flows than if TTM was initiated in an existing department with a long history of handling tools "the old way". Because the goal of the pilot was to prove out the TTM concept, and demonstrate its impact upon product cost and quality, we chose a department for which establishing the pilot represented a sizable, but not insurmountable, challenge. If we chose a very difficult environment for the pilot we faced the possibility of failing in our efforts. The down-side of such a failure greatly exceeded the benefits that could be accrued from the pilot's success in a more challenging environment. Failing to effectively establish the pilot would eliminate the opportunity to convince other departmental managers of the system's value - an important goal. And, because department managers were unwilling to provide the human resources to implement TTM, building a success story which could be used to market the system was critical. Building a successful pilot was also critical if TTM was to spread beyond TEP to other Chrysler facilities. By establishing a working pilot we would establish a showcase through which other Chrysler plants could become familiar with the concepts of tool management.

So, in choosing our pilot department we avoided departments which had a history of out-of-control manufacturing processes, and/or managers who were not receptive to tool management. In choosing the 3.5L head line we did not attack the bottleneck machining department at TEP. While successfully implementing TTM in the bottleneck would have provided the greatest benefits to TEP it was felt that the risk of implementing TTM for the first time in the bottleneck department brought with it a high likelihood of failure. The strategy of piloting TTM in the 3.5L head line mitigated the risk of failure by delaying implementation in the bottleneck department until TTM was debugged and proven.

5.1 Preparation and Team Building

Preparation for implementing the pilot began during the TTM design process. The system design went through many iterations and we worked with personnel from the 3.5L head department, support departments, and Union and plant management officials to create an efficacious system.

The core of the team consisted of Walt Durandetto, and myself. Walter, a Chrysler tool engineer, had previously worked in the tool room, and had spent almost twenty years at TEP in various capacities. As a result, Walter was familiar with the machining operations and the culture within TEP. He was able to bring to our design efforts a very good sense of what was, and what was not, feasible from an implementation stand point. Because Walter had a good rapport with workers and managers throughout the facility we were able to gain rapid feedback on our system design and implementation methodology.

As an outsider to TEP I complemented Walt's experience with a certain freshness in the way I viewed the organization and culture. This naiveté helped bring a new perspective to many of the problems we faced during implementation. I also played the role of analyst, working to evaluate the problem of tool management, and the impact of TTM, within a more analytical framework than typically employed at TEP. Between the two of us we possessed complementary experiences and problem solving skills that allowed us to bring the pilot to a successful conclusion.

In addition to Walter and I, Larry Deszell, job setters John Giampa (1st shift) and Reese Galimor (2nd shift), Tool Crib Team Coordinator (TC) Joe Martin, and cutter grinder Bill Nichols all played critical roles in the pilot implementation and the ensuing modifications to the TTM design. Because all of these people would be directly affected by TTM it was important to solicit their input and respond to their concerns. These five people did not meet very often as a single group. Instead, they met with Walter and I individually to work on problems related to the pilot implementation in the portion of the plant where they worked. Besides working out problems they provided critical feedback on the proposed implementation, and provided new ideas which were instrumental in designing and implementing the pilot program.

At the supervisory level, the plant's Tool Engineering Supervisor, and Manufacturing Engineering Manager, guided the project and ensured that its definition conformed to work standards and general guidelines for plant management. These personnel also helped us to obtain the equipment and labor necessary to build-up the pilot.

To conclude, the team which built TTM was a loose affiliation, with only two full-time members. The two full-time members held overall responsibility for the project and performed most of the required leg work. Additional personnel, mentioned above, represented constituencies that were served and/or affected by TTM. Frequent interaction with each of the aforementioned persons was required to insure that the program served all constituents as well as possible.

The following sections describe important developments during the launch of the TTM pilot in the 3.5L head line. Each section discusses the process of implementing the pilot in a specific part of TEP with its own well-defined behaviors.

5.2 3.5L Head Machining Department

To launch the pilot program, several modifications to the department's physical plant were required. The department was designed to use tooling as per current conventions, and unfortunately a lot of equipment which would be eliminated through TTM had already been purchased and installed by late July, when we began to prepare for the pilot. Before TTM it was expected that tools would be stored in tool boards at each station to facilitate the quick change of tooling when an unscheduled tool change occurred. As a result, cut-outs were made in the transfer-line safety fencing to accommodate the boards for each station. Because TTM requires that no tools are to be stored on the factory floor, these tool boards had to be removed. This meant that the holes remaining in the fencing had to be sealed up. This was done by welding mesh over the holes.

In addition to removing tool storage locations from the floor, our plan called for moving the department's job setter crib from its original location next to the department's transfer line to a location within the cutter grind department. Our rationale was that by moving the crib we would [1] gain greater control over inventories, [2] encourage department personnel to seek the root causes underlying tool problems by making it hard for them to feed large number of tools into machinery, [3] reduce the pressure placed on the job setters to provide machine operators with large numbers of tools, and most important we hoped to [4] create a strong relationship between the job setter and the cutter grinders, leading to improved quality tooling. In the longer term we hoped that as TTM expanded throughout the plant we could consolidate the job setter cribs into one area so that job setters could share equipment and skills.

Initially, moving the crib was opposed by the department's job setters, the cutter grinders, and UAW leadership. The job setters thought that being located so far from the department would make it difficult to respond to an unscheduled tool change in a timely fashion. They were also unhappy about the prospect of a ten minute walk each time a tool needed to be changed. Many of the cutter grinders opposed the idea on the grounds that management was attempting to have the job setters take on elements of cutter grind work, thereby replacing them with job setters. The cutter grinders were divided on this issue, and some felt that these complaints were rooted in a fear of change rather than any substantive concerns about job security.

The job setters agreed to try the new arrangement when provisions were made to ensure easy communication between the relocated job setter crib and the machining department. A phone was installed in the crib and the job setter was outfitted with a radio. These measures were unusual in that radios are usually reserved for managers, and phones are only found in manager's offices. Also, the job setters were provided a Cushman electric cart to enable quick trips between the crib and the transfer line. Nonetheless, when the crib was first relocated the job setters were convinced that it would be moved back to the department within one or two weeks.

The cutter grinders were less agreeable to the idea and took up the issue quite strongly with the Union once the crib had been relocated. This was disturbing because prior to the crib being moved we had worked extensively to ensure that all parties were at least willing to give the crib move a chance. We had met with the cutter grinders on several occasions and no strong objections had been raised. This may have been because the cutter grinders were unwilling to speak freely with representatives of management. Similar situations arose quite often during the course of the pilot project. We would try and discuss an idea for changing the physical lay-out of the plant, and almost no feedback from the workers could be obtained. Once the change had been implemented it would be protested. This differed greatly from the behavior experienced when changes in work rules, or job responsibilities were discussed. Workers provided ample feedback and were confrontational during discussions on these issues.

Discussions I held with workers on a one-on-one basis shed light on the reasons for the difference in behavior. Workers did not feel they had any control over management decisions regarding the deployment of capital (e.g. - machinery, and other technologies). Nor did workers feel they had any right to interact with managers to shape the plant's capital stock. The selection and implementation of new technologies, as embodied in physical equipment, was none of their business, nor did they want it to be. But, while workers were unwilling to interact with management regarding the selection of new technologies and equipment they did feel that the utilization of labor fell under their realm of control. Thus, as soon as a piece of capital equipment was installed and began to have an effect upon their work, laborers became quite active in lobbying for their interests.

So, we learned that in planning capital purchases and alterations to the physical plant, it is important to involve workers in these decisions, but on their terms. To illicit meaningful feedback from the workers, changes need to be discussed in terms of their impact upon working conditions. As an example, the fact that moving the job setter crib would allow us to keep better control of inventory was irrelevant to workers when measured against the fact that it would enable the job setter to inspect reground tools, a job that the cutter grinders are supposed to perform.

In working with the first shift job setter, John Giampa, to set up the pilot, we initially encountered many behaviors that were typical of the hourly workers in the plant. Giampa's initial dealings with us can be characterized as cordial but uncooperative. He made it clear that he thought the present way of doing things was working fine, and he resented having his routine disturbed. At the same time, he did whatever was asked of him regarding TTM, and would accurately answer any questions posed to him. Basically, John, and many workers, felt that management had attempted many improvement programs before, and each had failed, only to be succeeded by a new master plan which supposedly was the answer to all of the plant's problems. The goal of the workers was to try and weather the barrage of master plans as best as they could.

Over time, our persistence in pursuing the development of the pilot, and our unwillingness to let John be a passive participant, led to a change in his attitude. For example, when we first set-up tool trays for the department we were forced to use cardboard boxes to hold the trays. Each box was divided into compartments and labeled so that it could hold and identify several tools. We did this because the funds for plastic trays were not immediately available and it took several months to design and manufacture the exact trays need for the

3.5L head department. John's reaction to the boxes was one of ridicule. "They won't last a week," he said. He was right, but each week Walter and I made new boxes to replace those that had been damaged. Within two months John had taken it upon himself to collect the necessary boxes and organize them within his crib. Working with Tool Engineer, Larry Coffee, he also developed a better way of making the trays out of cardboard which greatly increased their life.

Once John realized that the responsibilities he had been assigned in TTM (e.g. - setting up the tools for tool changes, working with cutter grinders to fix tool grind errors, tracking inventory) were his alone, and that no one was looking over his shoulder, he became a positive force in shaping and defining the tool management system. He actively worked to improve tool quality and lower tool inventories, and strove to hone the performance of his portion of TTM. He generated many innovations in areas as broad as tool change scheduling, tool storage, and minimizing floor inventories.

During one of my visits with John in September, once the pilot was well under way, John talked about his enthusiasm. "I was bored doing the same thing every day. This is different, and I have to think about what I'm doing...Unfortunately in a few months this will be routine too." Statements like this one have led me to believe that much of the observed "laziness" on the part of hourly workers throughout the Big Three is caused by boredom, rather than disregard on the part of the employee for his work. Keeping workers excited about their work is a key to soliciting innovative ideas from the factory floor, and obtaining high quality productive work.

5.3 Cutter Grind Department

As described in Chapter Four, the design of TTM calls for several activities to be performed in the cutter grind department. These include the inspection of used tools for wear and the recording of wear values, the grinding tools in a batch of one, and inspecting the reground tools prior to returning them to the job setter crib.

The cutter grind department was generally hostile towards changes in their way of work. They believed that grinding the tools in a batch of one was not possible. Nor were they enthusiastic about measuring the tools for wear. Within the last few years the cutter grind inspector had retired and was not replaced. As a result, tools were supposed to be inspected by the person who ground them. TTM called for a dedicated individual to inspect tools for wear in order to off-load this work from the CNC grinder operator who was the TTM bottleneck. But, we were not permitted to add any additional staff to the department, nor did we see any need to do so given the department's work load. This meant that the remaining cutter grinders would need to shoulder additional grinding work. This became a major source of conflict between the TTM team and cutter grind personnel.

The biggest change required in cutter grind procedure related to the manner in which we ground tools. As was discussed in Chapter Four, our goal was to grind tools as they were removed from the transfer line without disassembling the tool from its holder. For the pilot we worked with a single person, Bill Nichols, to grind all of the 3.5L head line tools. This made it easier to monitor and revise TTM than if the grinding work had been distributed across several shifts and workers.

Fortunately, when the pilot began, the 3.5L head line had low production volumes. As a result, we were afforded a large amount of time, in excess of one week, between tool changes for most tools. Nonetheless, our grinding throughput was extremely low. And, even though 3.5L head production was low there were occasions when we were forced to expedite tools which were needed for an upcoming tool change through cutter grind. Low throughput was caused by TTM's batch-of-one grinding methodology. The amount of time to set-up the grinder for a particular tool type can be as long as 7 or 8 minutes, while grind times are usually less than five minutes. A flowchart of the set-up procedure prior to TTM is shown in Figure 5-1. Under TTM, tools are ground in small batches (maximum of three or four tools, and often only one tool) and a disproportionate amount of time is spent setting up to grind a tool as compared to the large batch grinding methodology. Under the large batch grinding system a batch of between ten and twenty tools would typically be ground between each set-up.

Projections for 3.5L head line production volumes indicated that set-up time would have to drop to about three minutes to insure that the cutter grind department could process enough tools for the head line as production volumes increased. We began the process of decreasing set-up time by designing new collets for the CNC grinder. These collets helped to reduce set-up time by decreasing the time required to select the proper collet (there were now only four choices vs. more than fifty) and by eliminating the need to knock the key from the tool holder before regrinding.

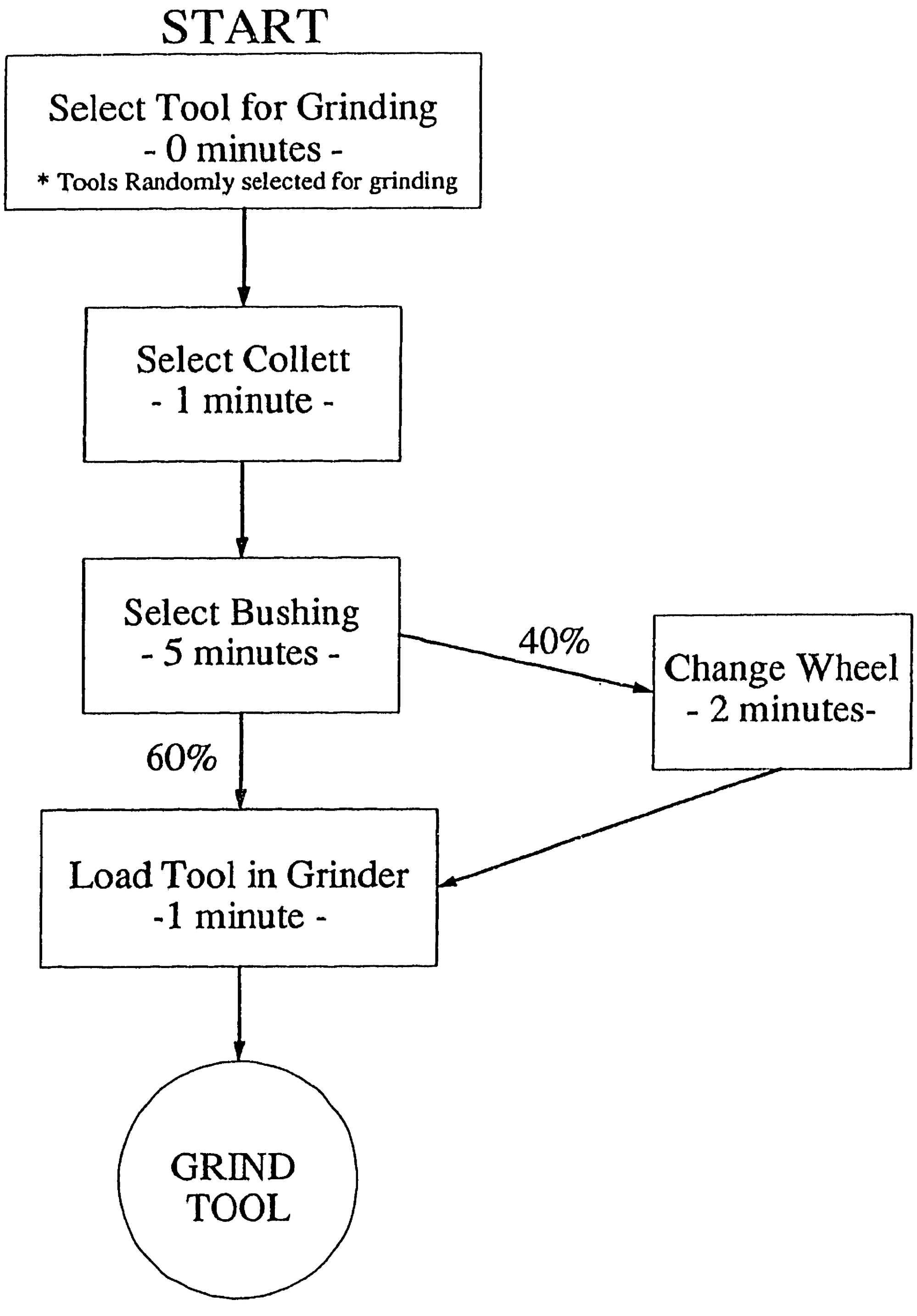


Figure 5-1: Flowchart of set-up procedure for grinding tools under conventional tool management system.

At this point Bill Nichols became actively involved in the effort to reduce set-up time. Having seen some of the benefits of TTM through his interactions with the 3.5L job setter, Bill was anxious for the program to succeed. An avid reader, Bill borrowed my copy of The Goal, by Goldratt, and within a week had fully digested it. He quickly recognized that tool grinding, and specifically the set-up procedures, was the bottleneck to TTM and he actively set about to reduce set-up time, requiring little guidance. With his new found motto, "Lengthen your Stride" now painted on his machine, Bill proceeded to reduce set-up time to under three minutes through the following activities. First, Bill organized the bushings used to support the tool tip during regrinding. There are over fifty bushings in use in cutter grind, one for every diameter tool in the plant. Before his efforts commenced these bushings were spread out over a table in no particular order. English and metric bushings were inter-mixed and choosing the proper bushing meant trying to fit the tool with each bushing until the proper match was made. This process was fairly random, and often took up to five minutes. In many cases the required bushing wasn't even present, having been removed from the table for another job and not returned to its place.

Bill recognized that this was a major time sink and had the carpenters build him a rack for the bushings. Each bushing sat on a nail on this board (much like a key board) and was located according to its size. Once the board was built and the bushings were properly arranged, Bill was able to locate the needed bushing in less than thirty seconds. Also, by looking at the board it became readily apparent if a bushing was missing.

Bill was able to reduce cycle time further by organizing the tools he ground in such a way as to minimize changes required on the CNC grinder. Bill grouped each batch of tools he received according to the grinding wheel that would be needed, and by the collet size required. In this way Bill could run all tools that required a particular grinding wheel-collet combination while only changing the bushing between tools. Once all of the tools in a wheel-collet group had been ground, Bill would change the collet or wheel, and run another group of tools. This effectively reduced set-up time by minimizing the number of wheel and collet changes required and represented a major improvement over our initial TTM methodology, in which tools were ground in a purely random order.

Bill also worked with John Giampa, the 3.5L first shift job setter, to prioritize the grinding of tools according to demand. Within each batch of tools that Bill received from the previous evening's tool change some would be required for a tool change within twenty four hours, while others would not be needed for a week or more. By ordering the grinding of tools in accordance with future tool change needs Bill was able to reduce expediting, reduce overtime requirements, and keep tool inventories low by balancing tool regrinding with 3.5L head production. Figure 5-2 shows the revised set-up procedure for tool grinding.

While the design and implementation of these changes was simple, the change in mindset that allowed Bill to recognize them as worthwhile innovations was far from trivial. By making Bill a stakeholder in TTM, and encouraging his active participation in the project, the entire plant was able to benefit from the application of his creative energies to the improvement of his work. Most important, each of the above enhancements to TTM was self-directed; neither Walter or myself managed these innovations. I believe that enabling workers throughout the plant to take actions like Bill did is a key element of manufacturing competitiveness. It expands the task of process improvement beyond the realm of plant management to the entire workforce. And, in doing so it allows the plant to benefit from experiences and insights which are difficult for plant managers to develop as compared to workers who have been intimately involved with a particular process for as long as thirty years.

5.4 Tool Cribs

In the initial design specification for TTM, laid out by Walter Durandetto and myself, there was no role for the wholesale or retail tool cribs. The functions carried out by the retail crib, principally tool storage, where to be handled by the 3.5L job setter crib on a reduced scale, and the wholesale crib operations were not encompassed by the TTM system. But, as we presented our initial design to representatives of the UAW it became clear that this was not an acceptable situation. They claimed that our plan would lead to the elimination of the retail crib, and therefore jobs, if expanded throughout the plant. We were told that we must include the retail crib in the TTM system. Given this constraint we began working with the crib personnel to define their role in TTM. As described in Chapter Four, the final TTM design utilized crib personnel to transport tools between the 3.5L job setter crib and the transfer line for block tool changes, and the crib personnel monitored the Ladder. These developments were straight forward, and as the pilot evolved the role of the tool cribs became increasingly critical to the success of TTM.

The tool crib was led by Team Coordinator Joe Martin, and the department had a long history of working to improve its operations. These efforts had met with limited success, in part because of external limitations placed upon their activities. For example, the

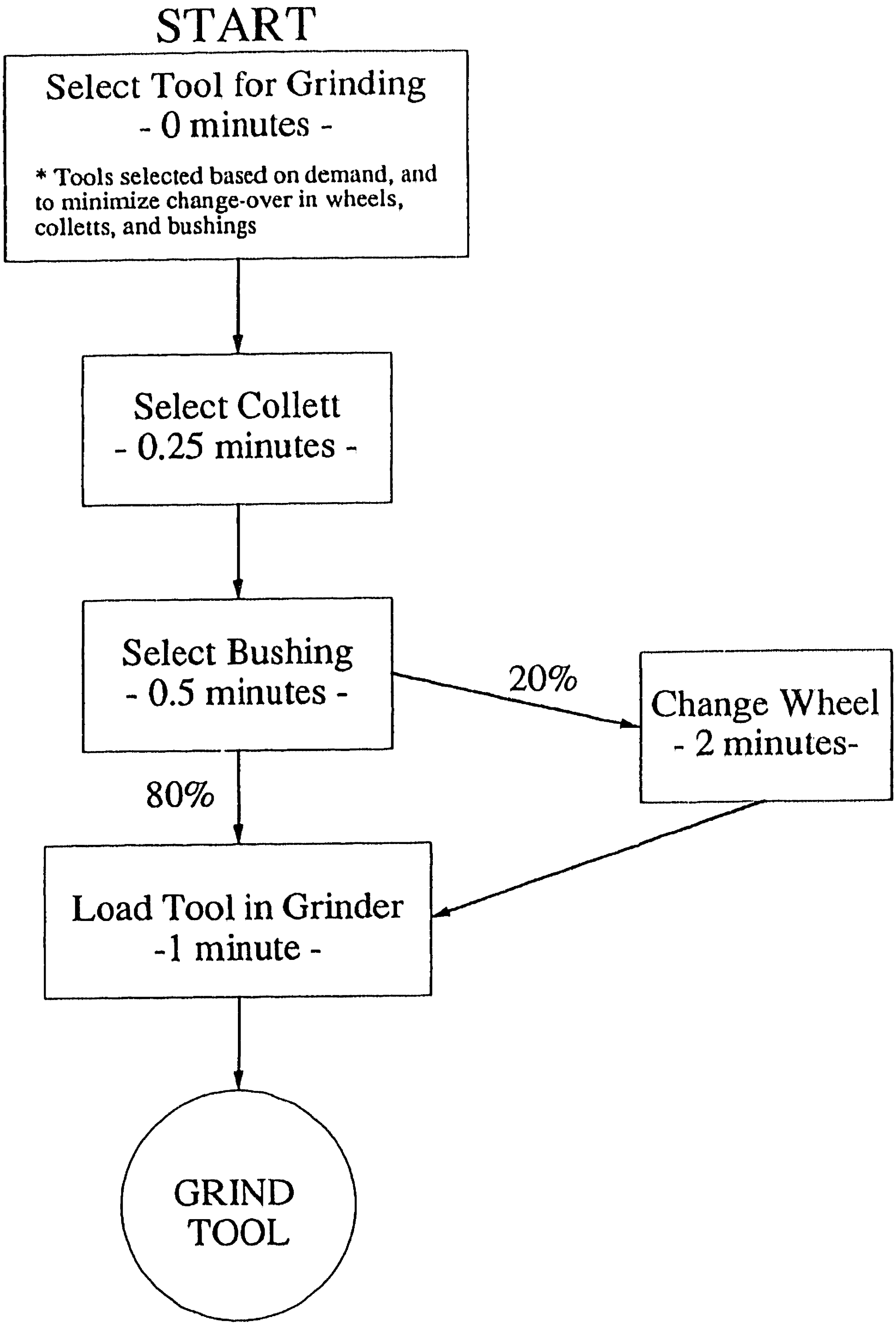


Figure 5-2: Flowchart of set-up procedure for grinding tools under Trenton Tool Management.

department had formed a team to investigate the activities of the plant's uniform suppliers. Crib personnel suspected that the plant was being overcharged for uniforms and felt that an adjustment in pricing was necessary. Their research revealed that the contractors had been charging TEP for damage to uniforms which the supplier itself had caused, and that the plant was being billed for uniforms which were not delivered. But, when the team presented its findings to higher management they were told to back off, and no corrective action was ever taken. Incidents like these had embittered the crib staff, and made them openly question the honesty and values of plant management. While many of them wanted to see conditions at the plant improve they were extremely skeptical of TTM, not because it wasn't worthwhile in and of itself, but because they felt that it was only a matter of time before managers withdrew support for some of its more unconventional, and important, aspects such as "The Ladder".

Thus, unlike other departments, tool crib personnel were generally motivated to improve conditions in the plant. Soliciting the involvement of tool crib personnel in the creation of TTM was not a matter of rousing the workers from a state of lethargy. Instead, the participation of tool crib personnel hinged on obtaining an air-tight commitment from upper management that their efforts would be supported over the long term.

One of the problems we faced when implementing the TTM pilot was the ease with which machining department personnel could obtain tooling through the "Underground Economy". The goal of our work with the tool crib was to eliminate the underground economy and ensure that all tools entering the plant moved through the proper channels. This meant that before becoming accessible to production personnel, tooling had to be properly received at the shipping area, checked into the plant inventory system, inspected, and stored in the wholesale crib. This goal was achieved through the creation of a DM/TBI policy.

Two classes of material that enter machining departments through the underground economy are material that has failed inspection (DM) and material taken before inspection (TBI). Working closely with Joe Martin, and a small group of tool crib personnel, we developed a procedure for eliminating the flow of these materials into the plant. Secured cages were built to store tools that failed inspection, and those that had not yet been inspected. By putting these tools under lock and key, and allowing only departmental managers to sign them out, we could ensure that if a department used tools that were of poor or unknown quality it was with the consent of the department's manager. Thus, our goal was not to prevent these tools from being used, as in many emergencies it was appropriate to do so, but rather to ensure that the decision to use DM/TBI material was made at an appropriate level. Prior to the institution of the DM/TBI policy it was possible for machine operators to enter the crib area and remove tooling without authorization, thereby creating uncertainty in the machining process and making it difficult for department managers and tool engineers to evaluate the performance of the machining process. In addition, these tools often led to the manufacture of scrap parts, and bloated the plant's tool inventory levels, because DM/TBI material that enters the floor is not recognized by any of the plant's inventory tracking systems. A copy of the complete DM/TBI policy can be found in Appendix B.

In creating the DM/TBI policy the tool crib personnel placed great emphasis on the need to obtain formal commitments from the plant's top managers supporting the policy. These commitments came in the form of signatures on the DM/TBI policy document. A portion of this document stated that none of the below signed managers would take action to usurp the policy, and that any orders given by these managers in the future which ran counter to the DM/TBI policy were to be subordinated to the procedure. In other words, the tool crib workers insisted that if they were going to manage a DM/TBI policy, and stand up to plant personnel who wanted DM or TBI tooling regardless of any policy which had been instituted, they wanted to be assured that they would not be undercut by plant managers who might be tempted to subvert the system to fight the plant's current fires.

To date this policy has worked quite effectively and upper level managers have not usurped it. And, while many department managers have griped about having to visit the crib personally to obtain DM/TBI material they have been willing to do so because they recognize the benefit of restricting access to this material. Prior to this policy many managers had been victimized by the unauthorized use of DM/TBI material in their department's machinery.

5.5 Tool Engineering

While our efforts to create local involvement in TTM were successful in each of the aforementioned departments, our attempts to integrate tool engineers into the TTM system were much less successful.

The tool engineering department consists of former members of the skilled trades arm of UAW Local 372. Most of the tool engineers were machinists or tool makers who were promoted into the tool engineering department. Traditionally, the role of the tool engineer has been to aid in the design of tooling, and to optimize the use of tooling in a machining department. In the past, one tool engineer was assigned to each machining department. Today, the tool engineering department has been spread thin by lay-offs and a reduction in new hires to replace retiring personnel. As a result, tool engineers are typically responsible for an entire class of departments, such as cam shafts, cranks, or cylinder heads.

Understaffed, the department presently spends its time trouble shooting tool-related failures and processing paperwork rather than establishing programs to provide systemic improvement of the plant's tooling performance. But, this lack of long-term focus is not caused by under staffing alone. The skill level of the plant's tool engineers is deficient with respect to engineering concepts and basic math skills. Some of the tool engineers are unable to solve basic trigonometry problems. These skill deficiencies initiate a vicious cycle in which tool engineers shy away from solving technically difficult problems because of a lack of skill and a low level of confidence in their own abilities. In turn, department managers do not feel well served by the tool engineering department and go outside the firm to tool vendors to solve tooling problems, depending on tool engineers only to handle clerical tasks like chasing down purchase orders. This then leads to tool engineering being held in lower regard by plant management, and fewer resources, in terms of both personnel and training, are allocated to the group. This in turn leads to a decrease in the competency and morale of the department and the cycle starts anew.

The current state of the tool engineering department is characterized by low self-confidence, extremely low morale, and a sharp cynicism towards any "new" programs. This cynicism has developed because many ideas that are presently trumpeted by plant managers as innovative were first generated by tool engineers, but were discounted by managers because they held so little faith in the abilities of the tool engineers. TTM is a case in point. Many tool engineers asked their managers to support an effort to develop a system for the rational management of tooling. These requests were either rejected outright or ignored.[14] But, when I came to Chrysler in June of 1992 the idea of tool management was being enthusiastically promoted by management. How frustrating that

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[14] Interview with Bill Anderson, Chrysler Corporation, Trenton, Michigan, 4 June 1992.

must have been to tool engineers who had presented the idea to plant managers several years ago.

Specifically, we found it very difficult to solicit tool engineer involvement with the TTM pilot, The TTM system calls for the tool engineer to review tool wear information, as well as unscheduled breakage reports, and to formulate a response to the department's worst tooling problems. During the pilot we repeatedly identified problem areas in the department before they became crises. And, when we approached the cylinder head tool engineer he agreed to address these problems but never followed through. We hypothesized that this was because he was uncertain as to how to proceed. Unlike his typical fire-fighting activities, we were asking this engineer to explore a problem that was just developing. It's characteristics were not well defined, and use of the scientific method was required to uncover the root causes of the observed condition In their typical mode of operation tool engineers do not solve problems by this method. Faced with a production crisis a tool engineer will typically change many elements of the machining process at once. His goal is not to discover the cause of the problem and prevent it from happening again, but to get the machine running NOW!

For example, one of the operations in the 3.5L head line used a series of T#1 reamers to form tightly toleranced holes. When reviewing our count sheets we noticed that these reamers were breaking fairly often relative to their scheduled tool change frequency. At present the problem was manageable because head production volumes were low. But, volumes were supposed to double in the near future and we were concerned that an increase in the number of unscheduled T#1 changes would limit production. We provided this information to the tool engineer and indicated to him that a major problem was in the process of developing.

The tool engineer responded to this problem by stocking about fifty reamers in the department near the machine so that they could be quickly replaced in the event of an unscheduled tool change. This was a breach of the TTM policy and these reamers were the first tools to be stored on the floor since the pilot began. Every so often he would bring worn tools from the department to cutter grind, expedite their regrinding and return the pile to the machining department. No analysis was made of the machining settings such as speed an feed, nor were the reground tools inspected to insure they were the proper size. The tool engineer hoped that by changing the tools the problem would go away. If this failed to affect the problem he hoped that by making it easier to change the tools when they broke (by piling up sharp tools in the department) he would reduce the impact of the problem on production. This didn't work either, and within one week the frequency of unscheduled T#1 changes had increased so that the department bottleneck resided in the machines using these reamers.

At this point we took control of the situation because we felt that allowing these tools to be managed outside of TTM would encourage others to subvert the system's procedures. Also, no progress had been made towards improving T#1 performance and production was adversely affected. To begin, we removed all of the reamers from the floor of the machining department. By subverting TTM the 3.5L tool engineer had made it difficult to accumulate any data about T#1 performance that could have been used to quantify the problem. We then put the reamers back into the TTM system, returning much of the inventory to the wholesale crib. What we quickly found, through cutter grind inspections that were a part of TTM, was that many of the reamers were undersize. By subverting TTM the tool engineer had actually made the problem worse by running undersize tools in the machining department. By ensuring that the proper size reamers were in use we gained a significant leap in tooling performance.

We then compared the feed and speed settings used for the 3.5L head reamers to the settings used for similar reamers in other departments. We found that the reamers in use in the pilot department had a slower feed and higher speed than reamers used successfully in other parts of the plant. We hypothesized that the reamers being used in the pilot department were going through the hole in such a manner that they heated the hole up and caused it to expand without adequately cutting the hole. Once the reamer passed through the hole the hole cooled and contracted. Then, when the machine tried to pull the reamer back through the hole it collided with the now undersized hole, breaking the reamer. We felt that by lowering the speed and increasing the feed we could rectify this situation.

To test this hypothesis we changed the speed and feed on half of the spindles using the T#1 reamer. Using TTM we were able to track reamer breakage within the experimental group as compared to the control group (half of the reamer spindles), and with this data we confirmed that by changing the speed and feed we could reduce reamer breakage to almost zero. TTM made this investigation easy because tool performance data is collected as a matter of course for each spindle in the system. No specialized procedures are required to test tool performance.

While we were glad to have been able to solve the problem, we were concerned by the fact that the problem could not be addressed by the department's own tool engineer. Nor were we confident that other tool engineers in the department would have handled the problem more competently. This was of great concern because to obtain many of the benefits provided by TTM, tool engineers must use the data provided to systematically attack and eliminate tooling problems. When TTM made quality tool performance data available another problem was uncovered, namely the inability of tool engineers to use this data to improve tooling performance. This underlying weakness went unnoticed in the past because tool performance data was not generally available. As a result, it was difficult to create a controlled experiment to evaluate tooling performance. Without this information, simultaneously changing every possible input to a problem may have been an acceptable methodology, especially given the fact that most problems being addressed were crises that required immediate attention.

5.6 Interaction with UAW Local 372 Leadership

One of the more interesting aspects of the pilot implementation was our interaction with leaders of UAW local 372. When we began designing TTM we made numerous efforts to bring Union leadership into the design process. We hoped that by gaining their input up front we could create a better tool management system, and avoid conflict with the Union over work rules.

Unfortunately, we found that the Union Committeemen and Stewards were unwilling to partake in the design process during its formative stages. First, they were very busy addressing the concerns and grievances of their members. Second, they did not maintain any office hours and it was very difficult to find them during the day, let alone have them commit to a meeting time and place. The Union leadership's management style was very much "management by walking around", and as politicians they felt it was important to constantly be on the floor.

But, most important, Union leaders were unwilling to take part in the design of TTM because they felt more comfortable in an adversarial relationship with management than in a collaborative one. Thus, they would rather critique TTM after we had designed it, than to help to create it in the first place. They took this stance because they were wary of appearing to be too close to management, and by holding the right of last refusal the Union could determine which projects would be implemented and their final form. If the

Union had agreed to be involved in the project's development from the beginning they would have relinquished much of their bargaining power.

Once the Union completed its critique of the TTM pilot, and we made the necessary adjustments, we set up a weekly meeting where Union Leaders could meet with us and the Manufacturing Engineering Manager (our supervisor) to discuss their concerns. The first week, one out of ten invited UAW leaders came. Over the next 13 weeks no one showed up to the meeting, and we never heard from the Union on the issue of TTM again. At no time during the pilot, or during its design, did the UAW leadership question the efficacy or value of the project. Beyond the direct impact it would have on their membership they showed no interest in understanding TTM or contributing their knowledge to its formation.

Overall, we were disappointed by our interactions with the Union. While we expected to have disagreements, we hoped that there would also be positive interaction which could improve TTM. Unfortunately, we were never able to benefit from the skills and expertise of the Union leadership, no matter how we solicited it. Many aspects of the UAW-management relationship which we experienced at TEP can be explained by the great differences in skills and perspective held by managers and Union leaders at TEP. UAW leaders and managers have different backgrounds, measure success on different terms, and serve different constituencies. Only by creating a set of common experiences for UAW leaders and managers do I think that meaningful cooperation between these parties can be achieved.

6.0 Performance of the 3.5L Head Line TTM Pilot

This chapter presents the August to December 1992 results of our pilot project in the 3.5L head line. Because of the sensitive nature of the results, a complete picture of the benefits provided by TTM can not be presented in this document. Instead, we will look at a more narrow set of measures which still give the reader insight into the benefits of the Trenton Tool Management system. Chrysler personnel who would like additional information can contact Walter Durandetto at Trenton Engine Plant or Miles Arnone at Kokomo Transmission Plant.

The performance measures presented here include unscheduled tool changes, traceable tooling inventory, and lost production. In the case of tooling inventory, a comparison will be made to existing head lines within TEP that operate with conventional tool management practices.

In addition to these performance measures, examples of how TTM was used to improve the tooling performance of the 3.5L head department will be provided. These examples help to illustrate how the information provided by TTM can be used to identify and improve areas of poor tool performance.

6.1 Performance Measures

All of the succeeding data regarding TTM pilot performance should be evaluated with the following in mind. First, the pilot department was a new department. As a result, most of the machinery and processes in use were in control. In and of itself, applying TTM to a department which has poorly performing equipment and processes will not provide all of the benefits described below. But, TTM will enable improvements to be made in departments which are out-of-control by providing a framework for scientifically exploring and correcting process related deficiencies. Thus, TTM enables a machining department to approach its true productive potential to an extent that is not possible when traditional tool management practices are in place. These process-based improvements not withstanding, TTM does provide tangible benefits through the reduction of tool inventories and costs, and these results can be obtained across a wide range of departments.

General Comparison of Performance - TTM vs. Traditional Tool Management

To compare the performance of TTM to traditional tool management methods we can measure the performance of the 3.5L head line under TTM and compare it to the department's expected performance under conventional tool management practice performance estimates for traditional practice are derived from the studies outlined in Chapter Three and represent the application of those practices, as observed in other head machining departments, to the 3.5L head line.

Table 6-1 compares TTM pilot performance to what would be the 3.5L head line's performance under conventional tool management practice. Four measures are presented. FLOAT and PREMIUM are as defined in Chapter Three, while lost production is a dimensionless stand-in for OCP, and Scrap & Rework is the percentage of all heads processed that required repair or had to be discarded as a result of tool failure

Table 6-1: Comparison of performance of 3.5L head machining department under TTM, and as expected under traditional practices.

	Tool Management System	
Performance Measure	TTM	Traditional
FLOAT	1.6	4.2
PREMIUM ($000)	0	11.6
Lost Production	6%	11%
Scrap & Rework	1.5%	4.7%

Under TTM, the 3.5L head line carried tool inventories 1.6 times as large as those predicted by the float sheets as necessary to sustain operations. While this number is significantly less than the 4.2 typically observed when using traditional tool management it is still disturbing because the estimate of 4.2 is based on conditions in TEP's two other headlines, which have been in operation for many years. But, in fact, the value of FLOAT for the 3.5L head line has been decreasing ever since the beginning of the pilot, and should level out at or below one. This is because when the department was started-up in late July a large amount of tooling, in excess of float sheet requirements, had already been purchased. The transfer line was delivered with three sets of tools for each spindle, and the plant purchased tools to cover the float sheet values in addition to these tools. With TTM in operation, tool consumption in the 3.5L head line has been very low, and so over time the amount of inventory maintained in the plant for the department has shrunk, leading to the decrease in FLOAT. It should be noted that during the pilot, inventory levels outside the wholesale crib remained essentially constant due to the controls established by TTM.

During the pilot the no premium purchases were made. This attests to the effectiveness of controls such as the "Ladder" at alerting department managers and tool engineers about tools which were being consumed at a high rate. This measure also points to the value of maintaining a tight control over inventories and keeping inventory off of the factory floor. By so doing we knew the true amount of pilot tooling present in the plant at all times. The value of $11,600 for traditional tool management methods is the average annual premium tool purchases per department pro-rated for the time frame under consideration.

The value of 6% for lost production time does not correlate directly to a 6% decrease in department output. Rather it is a measure of the time required for unscheduled and scheduled tool changes compared to the time allocated for production. It does not relate directly to lost throughput because this data does not indicate the location on the transfer line where production was halted as a result of an unscheduled tool change. Only with this knowledge can the lost production value be used to determine the amount of over-time required to make up lost output. Nonetheless, this value does give us an estimate of the frequency with which production is interrupted because of tooling. For the TTM pilot this value was calculated by multiplying the number of tool changes made by an average tool change time. This product was divided by allocated production time. For the traditional tool management scenario, values obtained from a previously undertaken study of head line performance were used.[15]

Scrap & Rework values were obtained by summing the number of unscheduled tool changes that occurred in the pilot and comparing this value to the department's production volumes. For the purpose of this assessment we assumed that each time an unscheduled tool change was made a machined part was in some way damaged. Either a tool broke in the part, damaging it, or the feature made by the tool was not the correct size. This

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[15] Rommelaere, p. 14

estimate is somewhat conservative and so the Scrap & Rework values for both scenarios are slightly overstated.

Unscheduled Tool Changes in the TTM Pilot

In designing TTM we strove to reduce the number of unscheduled tool changes required. Unscheduled tool changes are detrimental because they directly affect several aspects of department performance, including parts manufactured, scrap rates, over-time labor requirements, production costs, and conformance to standard costs. By reducing unscheduled tool changes we can directly improve the 3.5L head line's performance by enabling more heads to be manufactured at a lower cost.

On a more elemental level, the number of unscheduled tool changes reflects the degree to which the system for managing tooling can ensure tool quality. If tools are changed before they are over-worn, and only high quality tools are provided to the department, the number of unscheduled tool changes should remain low. If, on the other hand, tools are changed haphazardly, and there are no means of monitoring tool quality, we would expect to see a large number of unscheduled tool changes.

Figure 6-1 presents the number of unscheduled tool changes per week over approximately six months of the TTM pilot. Note that during October the number of unscheduled tool changes leapt to almost 80 tools per week, or about 11 per day. This period corresponded to the difficulties encountered with T#1 reamer performance, as described in Chapter 5. In late October, when we brought this problem under control, the number of unscheduled tool changes dropped dramatically. But, in and of itself this figure does not provide an accurate representation of the situation. Figure 6-2 illustrates the number of unscheduled tool changes as a function of the 3.5L head line's production volumes. Throughout the six months of the pilot, production volumes increased, and as Figure 6-2 shows, the rate of increase of unscheduled tool changes lagged this growth. In fact, by the end of October the system had reached an apparent equilibrium. We expected one unscheduled tool change for every 100 heads manufactured and hope to achieve additional improvement beyond this level in the future as a result of manufacturing process improvements.

These values compare very favorably to the number of unscheduled tool changes in TEP's other head lines. But, direct comparisons are difficult to make because in the case of the other head lines there are few "scheduled" tool changes. Almost all tools in these departments are changed as a result of a change in part dimension or a tool failure.

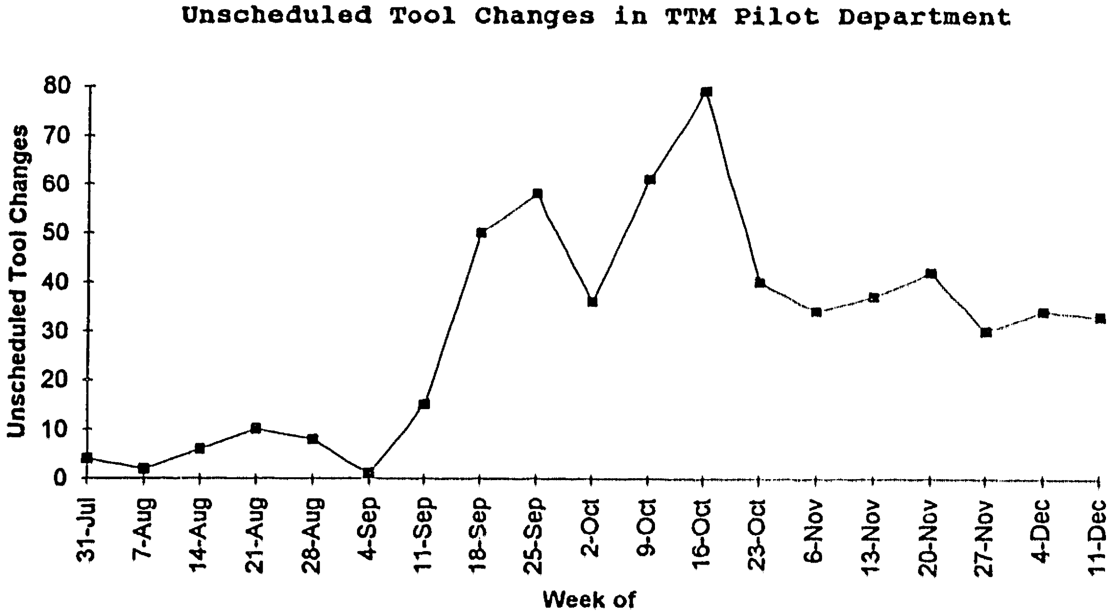

Figure 6-1: Unscheduled tool changes in the TTM pilot department, the 3.5L V-6 cylinder head line.

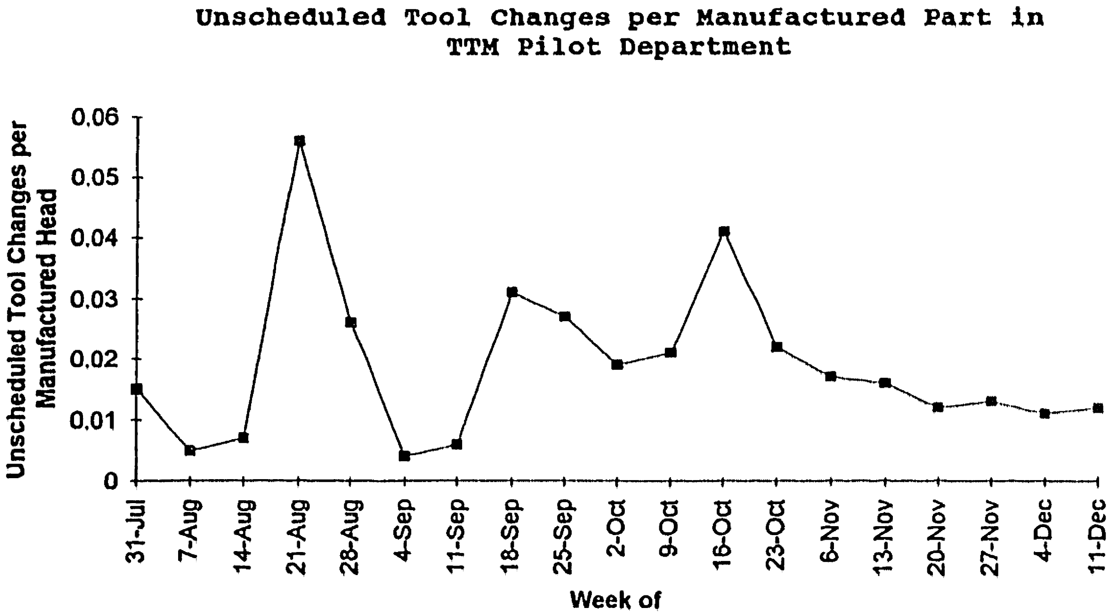

Figure 6-2: Unscheduled tool changes per part manufactured in the TTM pilot department, the 3.5L V-6 cylinder head line.

Block tool change procedures are not used in these departments. As a result it is difficult to distinguish a "scheduled" tool change from an "unscheduled" tool change.

Tool Inventories

Another important measure of TTM performance is the amount of tool inventory required to support the department's operations. To evaluate the impact of TTM upon tool inventories we created an index of tools which we could trace during the pilot. In addition to tracing the total inventory levels for the tools in this index we tracked the location of these inventories. Figure 6-3 shows the dollar value of tool inventories within the index for the 3.5L head line. Note that over the two and one half months for which we accumulated data total index inventories held steady, and that the value of wholesale inventory represents a significant proportion of the total inventory. This is important because these inventories are secure, and are effectively off-limits. Thus, the department requires only about half of the total amount of tool inventory in order to operate. Further, the dollar value of tool inventory in the retail crib and on the factory floor is extremely low. This reflects our efforts to consolidate the storage of inventory to enable the tracking of tool performance and ensure the quality of tooling used in production.

Figure 6-4 presents the value of inventory as a function of the 3.5L head line's production volumes. This figure shows that as the pilot progressed we were able to produce more heads without a corresponding increase in tool inventory. Again, these values compare favorably to inventory levels in the plant's other head lines.

Figure 6-5 shows the dollar value of tooling on the floor of the 3.5L head manufacturing department. The dollar values presented correspond to fewer than ten tools being present on the floor of the department. In other head machining departments the dollar value of inventory on the floor can approach 50% of the total tool inventory for the department. Figure 6-6 presents the floor inventory with respect to the production volumes in the department. Again, inventory growth lagged the increase in production volumes. The key point made by these figures is that floor inventories are extremely low, and as a result we can expect the tooling used in the department to be of high quality. Over-worn, or incorrectly dimensioned tools, are unlikely to find their way into the transfer line, and when tooling problems arise, knowledge about the situation is much more likely to spread beyond the operator of the machinery. This measure, floor inventory, is perhaps the most critical in evaluating the success of a tool management system.

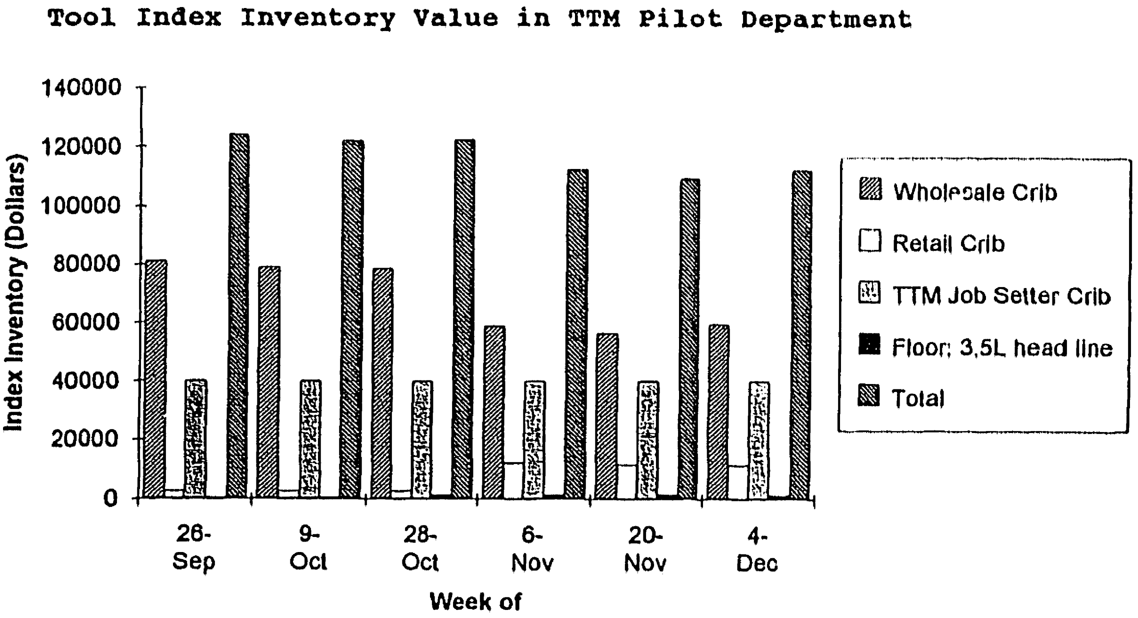

Figure 6-3: Value of tool inventories dedicated to 3.5L V-6 cylinder head production by storage location.

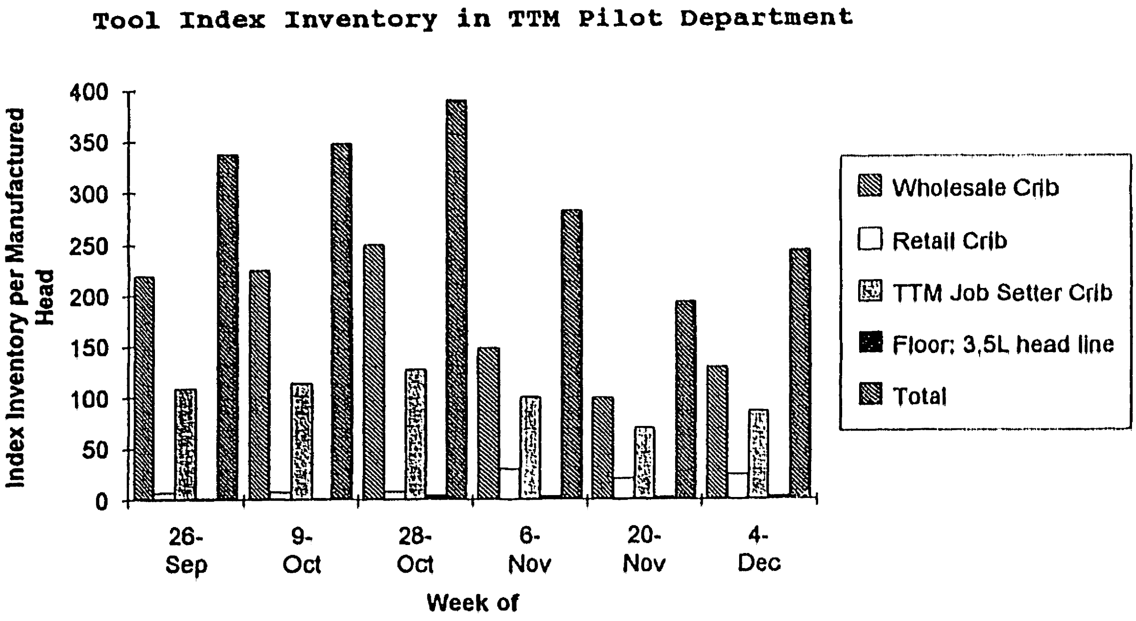

Figure 6-4: Value of tool inventories dedicated to 3.5L V-6 cylinder head production per part manufactured.

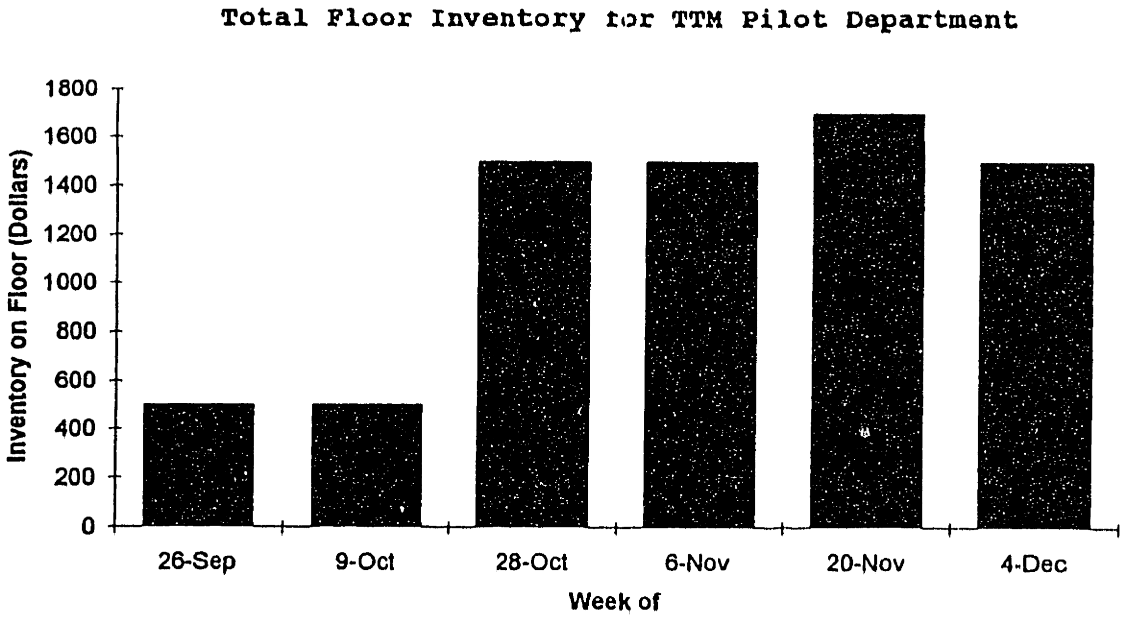

Figure 6-5: Value of tool inventories located on the floor of the TTM pilot department.

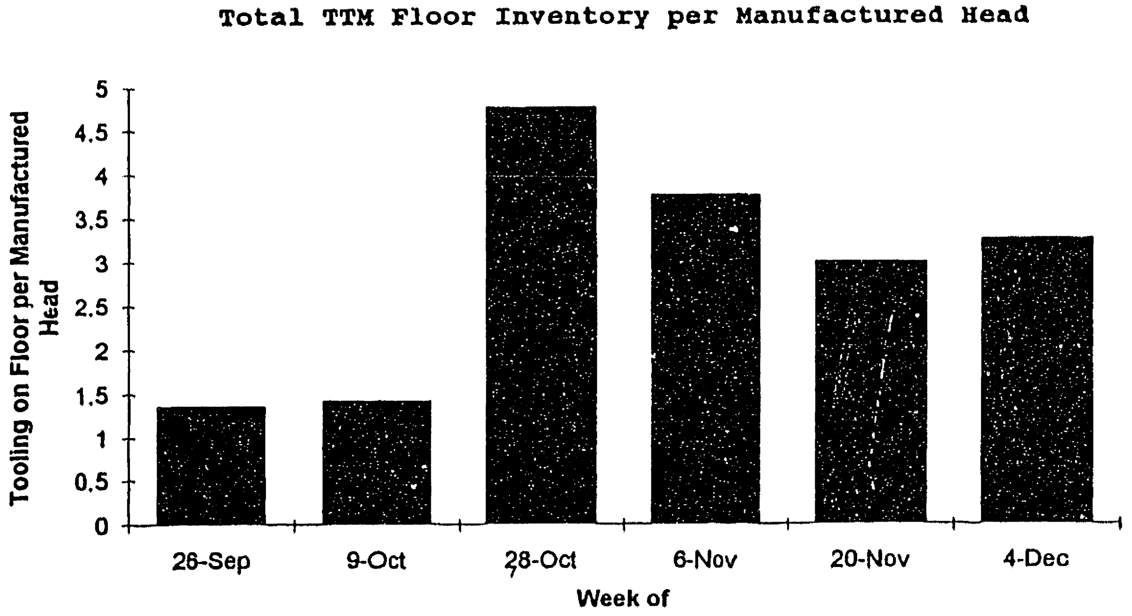

Figure 6-6: Value of tool inventories located on the floor of the TTM pilot department per cylinder head manufactured.

If tools are not accounted for, tool inventories will grow at alarming rates and the quality of tooling will become an unknown. These figures indicate that under TTM we have a good handle on both tool inventories and tool-related information.

Inventory Comparison: 3.5L head line vs. 4 cylinder head line

While the above data concerns only the TTM pilot department, a comparison between the pilot and a department using traditional tool management is instructive. We compared the inventory levels, and location of inventories, of tools used in the 3.5L head line against comparable tools used in the 4-cylinder, 2.5L head line. Despite the differences in age and part processing between these two lines we can compare tools used in them because when we compare tool inventories we are not evaluating the efficiency of the transfer line, but rather the tool management systems that surround each department. To make the comparison we need to look at tools that cycle out of the machines from each department at the same rate. For example, if the 4-cylinder line makes 2X heads per day, and the 3.5L head line makes X heads per day, then we can only directly compare the inventory of tools across these departments when the tool life of the 3.5L head line tool is half that of the tool in question from the 4 cylinder line. Then, both of these tools will cycle out of the transfer line at the same interval with respect to time.

An example comparison is presented in Figure 6-7. This figure shows the location of inventories for two comparable tools, one from the 2.5L four cylinder head line (Department 424) and the other from the 3.5L V-6 cylinder head line (the TTM pilot). Note that in the TTM pilot department inventory is only stored in two locations, while in the department using traditional tool management, inventory is stored in four locations. Also of interest is the fact that about half of the 424 tool's inventory resides on the floor, while none of the TTM pilot department's tooling is found in the uncontrolled environment of the floor.

Figure 6-8 takes this comparison further by illustrating the total inventory of these tools for each department, and then showing the number of tools in inventory per spindle on which the tool is used. In department 424 there are over 17 tools in inventory for every one tool in use in the transfer line. In the TTM pilot there are approximately four tools in inventory for every spindle in which this tool is used. Again, these vast differences in inventory exist even though these tools are changed in their respective departments at approximately the same frequency.

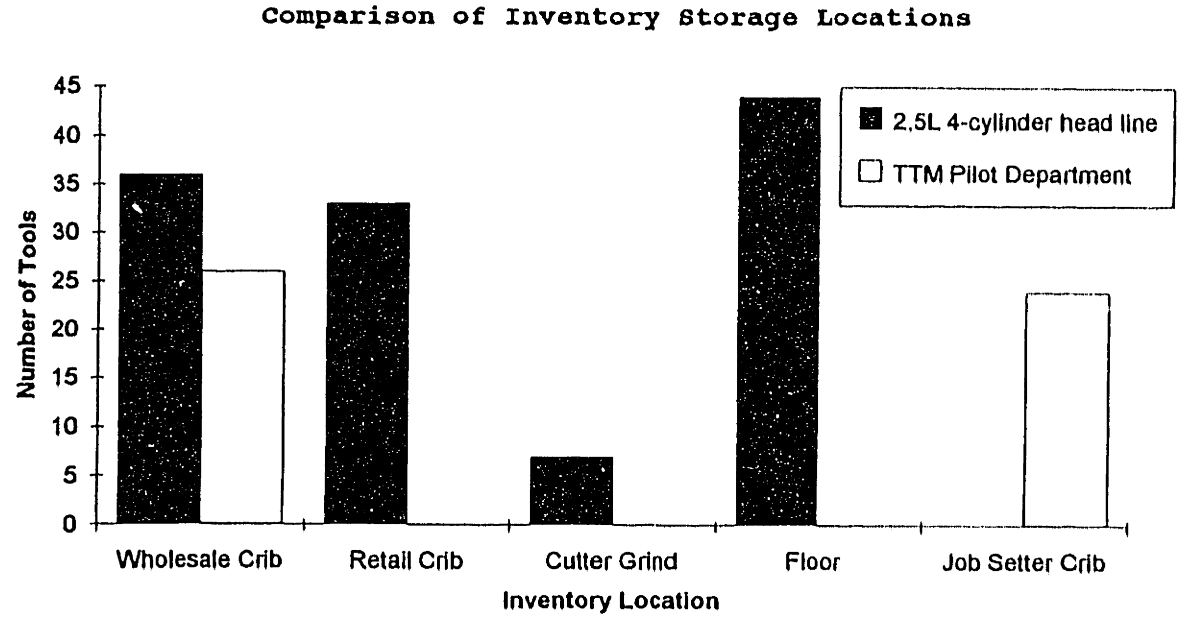

Figure 6-7: Comparison of inventory for two drills, one used in the 2,5L four cylinder head manufacturing department, and one used in the TTM pilot. These two tools exit the transfer line in each department at the same rate.

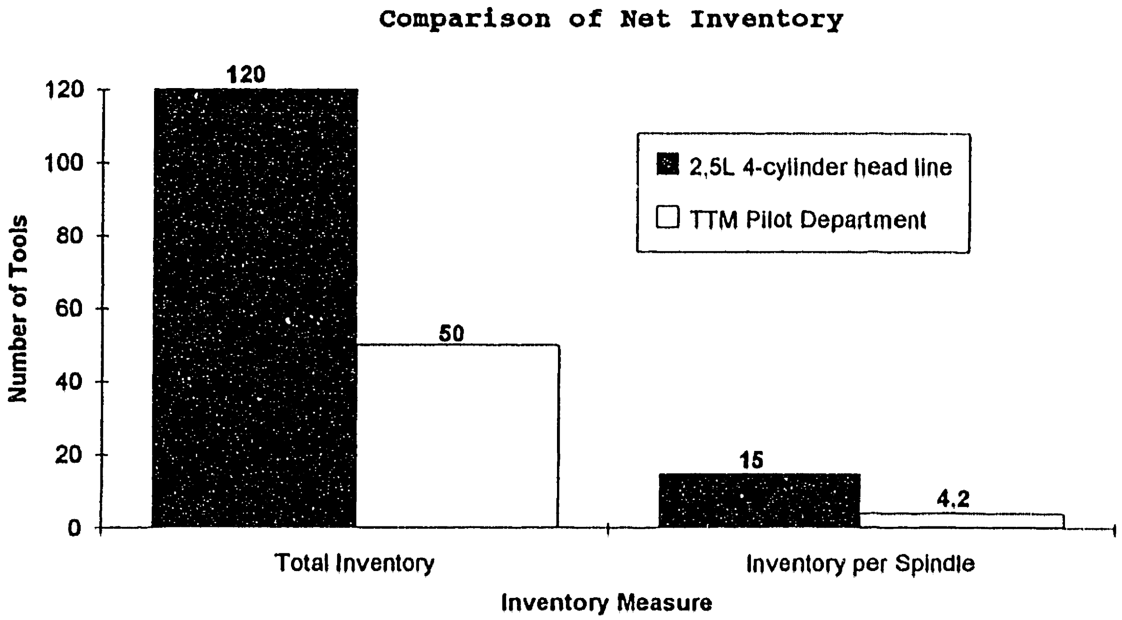

Figure 6-8: Inventory comparison between the TTM pilot and the 2,5L four cylinder head manufacturing department.

While the inventories for the 4-cylinder head line tool are above average for that department, they are typical in several ways. First, for tools used in a traditional tool management environment, a substantial proportion of the inventory is on the factory floor where it is unrecognized by the plant's tracking systems and where its quality can not be assured. Second, tool inventories are typically stored in five locations under traditional tool management systems. This leads to a higher total inventory level as compared to TTM, which makes use of only two inventory storage locations. Finally, the inventory per spindle in a department using traditional tool management systems ranges widely across spindles, from less than two tools per spindle to over thirty tools per spindle. Thus, at any given time there are some tools which are in chronic short supply, and others for which there are incredible surpluses. In short, the plant's resources are not effectively distributed under conventional tool management systems.

The inventory values for the TTM pilot presented in Figures 6-7 and 6-8 are typical in that there are only two inventory locations. And, more importantly, the value of about four tools in inventory per spindle is essentially constant across all spindles in the TTM pilot department. By keeping this value consistent and low, the plant's resources are conserved, and a state of tension is created so that the use of tooling must be monitored closely at all times to prevent shortages. Unlike traditional tool management systems, TTM does not afford its users the costly "safety net" of ten or twenty tools in inventory per machining spindle.

6.2 Continuous Improvement Case Studies

The results presented above can be used to evaluate the effect of TTM upon tool inventories and performance, and to a lesser extent they can be used to gauge the impact of TTM upon overall 3.5L head line performance. But, if we focus only on the end results of TTM we will miss one of the system's key benefits. In addition to reducing tool inventories and consumption directly, TTM provides a means of identifying the root causes of problems in the transfer line. As was discussed in Chapter 2, the tool is the weak link in a structural loop consisting of the machine tool, spindle, tool, fixturing, and workpiece. Used properly the tool can serve as a means of diagnosing production problems in the transfer line. Unfortunately, in conventional tool management the tool serves as a scape-goat for manufacturing problems, and as a result the root cause of the problem is often not discovered until much later, when, after having consumed a large number of tools, managers realize that the problem extends beyond the tooling.

TTM enables a diagnostic function to be performed via its tracking system. Every spindle is treated as a separate entity, and tools are used on only one spindle throughout their entire useful life. This methodology, combined with the information feedback loop created by the tool wear measurement process, means that TTM can be used to establish levels of adequate performance for each spindle regarding tool life and wear. When performance strays from these standards a flag is raised that a manufacturing problem is developing. Also, because spindles using the same tool number tools each have their own tool supply, we can compare performance across spindles using the same T# tools and performing the same cutting operations. This makes it possible to identify deterioration in the manufacturing performance of one or more such spindles which are a part of a group of identical units.

Two particular examples illustrate the power of TTM's process improvement capabilities. The first example illustrates how TTM makes it possible to use unscheduled tool change data, which is kept on a spindle-by-spindle basis using the count sheets, to identify potential machining problems. Appendix C contains a memo, dated September 1, 1992, sent to the 3.5L department manager from the TTM team. This memo is typical of the way in which we communicated trends of interest to production management during the TTM pilot. This function has been handled increasingly by participants in the TTM pilot including the job setter and cutter grinder, as opposed to Walter and myself.

The first part of the memo outlines tool change activity for the department and highlights recent pitfalls and successes. The last section, "A Tooling Problem" reports on the identification of a manufacturing problem. The tools used in a particular spindle, OP20A-ST13RH-#131, were breaking at a high frequency. The same tool used in this spindle was also used in five other spindles, yet the number of tool breakages for spindle #131 exceeded breakage levels in the other five spindles *combined*. This indicates that the tool itself was probably not at fault, but rather that there was a problem with the specific equipment in use at OP20A-ST13RH-#131. Appendix C also contains a follow up memo written the next day. A vibration analysis of the #131 spindle indicated that in fact the spindle was not performing properly. The vibration analysis indicated that the spindle may have undergone a loss of pre-load, and when the spindle was replaced this hypothesis was confirmed. Once the spindle was replaced breakage of this tool decreased to the extent that it was no longer a problem.

This example points to the power of TTM's tracking capabilities. Under traditional tool management systems there would have been no mechanism for linking tool breakage to a particular spindle. As a result, the only conclusion that could be drawn by a tool engineer is that the tool was at fault. And, while the #131 spindle problem may have been identified eventually, many more tools would have been broken in the interim, and a more expensive problem solution, such as replacing all spindles that use the tool in question, probably would have been pursued.

The second example explores the use of TTM to structure experiments for improving tooling performance rather than using TTM to discover problems as in the first example. As per Chapter 5, during the middle of October the 3.5L head line was struggling to meet production requirements because of inadequate performance of T#1 reamers. We wanted to test our hypothesis that the speeds and feeds for the reamers in the pilot department were improperly set, and that the reamers presently in use in the department were over-worn. TTM treats every spindle as an independent traceable item, and provides feedback on tool performance through wear measurements and by tracking unscheduled tool changes. As a result we were able to design an experiment to test our hypothesis regarding speeds and feeds, and at the same time evaluate the sensitivity of the machining process to dull reamers.

We created a control group and three experimental groups by dividing the spindles using the T#1 reamers into four sets. The first would use worn reamers at the existing speed and feed settings. This group served as our control group. The second group used worn reamers at the new speed and feed settings. The third group used new reamers at the old feed and speed settings, while the fourth group used new reamers at the new speed and feed settings. We then ran the transfer line with these experimental groups, and as a matter of course TTM recorded the number of tool breakages on a spindle-by-spindle basis. The results of the experiment are presented in Table 6-2.

Table 6-2: Results of reaming process experiments.

Group	Reamers(New, Old)	Speed/Feed(New, Old)	Breakages
1 (control)	Old	Old	14
2	Old	New	7
3	New	Old	9
4	New	New	0

From these results we were able to demonstrate the importance of keeping the reamers off of the factory floor, and the benefit of changing the speed and feed for the machining process to the recommended values.

The use of TTM to manage an experiment in this fashion is significant because TTM collects the necessary data as a matter of course. All we needed to do was create the experimental groups, by changing tools or machining parameters, and then compile the collected data. Under traditional tool management systems every experiment requires an incredible amount of effort to collect data, and often the data obtained is not reliable. This greatly hampers continuous improvement efforts under these traditional systems.

Using TTM a broad range of experiments can be easily set-up and run. New tool geometries and materials can be evaluated, machine settings (e.g. - speed, feed, depth of cut, etc.) can be optimized, and the impact of changes in fixturing and workpiece design upon manufacturability can be readily evaluated. These investigations are all made possible by the ease with which data is collected through TTM, and because of the high quality of that data.

Thus, we see that TTM can play two broad roles in improving the manufacturing process. First it can serve as a diagnostic tool by helping to identify inadequacies in the manufacturing process, and identifying the root causes of manufacturing problems before they bloom into large problems. Second, TTM can be used to structure experiments for the purpose of improving the manufacturing process. This is made possible by the integrity of data collected by TTM and the ease with which this data can be collected.

7.0 Blueprint for the Expansion of Trenton Tool Management

The previous chapters outlined the design of the Trenton Tool Management system, and its application to the 3.5L head line. As the first six months of the TTM project drew to a close we worked to lay the groundwork for TTM's continued evolution and broader implementation. This chapter outlines this effort.

7.1 Tool Management Team

As previously discussed, TTM was designed and piloted by a loosely affiliated team. At the core of this team, Walt and I worked full-time administering the system. Once the pilot was firmly established in the 3.5L head line we began to draw up plans for expanding the system into other parts of the plant. But, in order to expand the system while maintaining the pilot operation, additional man-power was needed.

Working with the Tool Engineering Department Supervisor, and the Manufacturing Engineering Manager, we were able to assemble a Tool Management team of four full time tool engineers. Despite a man power shortage in tool engineering, the Mechanical Engineering Manager was willing to allocate manpower to TTM because he recognized that an investment was required now (a reduction in the tool engineering department's ability to respond to tool crises) to gain improved performance in the future. In principal, the engineers assigned to TTM were relieved of their day-to-day duties to focus on the expansion of the tool management system. Upper-level plant management supported this move because there were several departments in the plant which were performing below expectations, and it was hoped that implementing a tool management system in these areas would improve their performance.

The tool management team included Walt Durandetto, and three other full-time members. One of the team's new members, a long time tool engineer joined the team enthusiastically, and believed that TTM could bring the plant significant benefits. Another team member, who had been promoted from the floor to tool engineering only one year earlier, was less enthusiastic in his support for the project. He found it hard to accept the premise that TTM was more important than the day-to-day activities that he was now performing, and worried that by dedicating his time to TTM the departments he previously supported would suffer in the short term. This engineer was also less confident than the others of his ability to understand, and promote, the program to production managers in the plant. The final member of the team was chosen for the program because in management's view he was not performing his duties to the level of his abilities and it was felt that a "change in scenery" might motivate him to take a more active role in his work. It did not, and after two weeks this member quit the team to return to his previous tool engineering duties.

Once the team was established in late November, we dedicated approximately two weeks to training the new team members about TTM. This training involved spending time in cutter grind and the job setter crib, and working with Walter and myself to schedule tool changes, and evaluate tool performance. The new team members also spent time with the vendors who were supplying TTM with equipment. By December the team was ready to expand the program to other departments. But, our efforts to expand the TTM system were hampered by the difficulty we had in distancing the TTM tool engineers from their previous duties. The department's they previously served still called on them repeatedly, and when crises arose it was almost impossible to shift the work onto other tool engineers. Also, the fact that the TTM tool engineers had developed many inter-personal relationships with managers in the production departments they formerly served made it difficult for them to refuse these manager's requests for support.

7.2 Automation of the 3.5L Head Line Pilot

The pilot operation established in the 3.5L head line brought with it a lot of paperwork. Count sheets needed to be updated manually, and tool change schedules were generated each day by one of the TTM team members. Close monitoring of tool performance data was also required to identify potential tooling problems. Throughout the first six months of the pilot the "manual" quality of the TTM operation was a benefit. It made it easier for all parties to visualize the system (data did not "mysteriously" move around within a computer) and it was possible to question the logic of tool scheduling policies and other procedures because the manner in which they operated could be easily observed. Also, because all of the data manipulation in the TTM pilot was manual we could easily educate newcomers about the system.

But, once the system was refined, and a critical mass of knowledge about its operation had emerged, the manual data handling operations threatened to tie up TTM personnel who were needed to expand the pilot beyond the 3.5L head line. To address this problem we worked closely with Royal Design and Manufacturing to embody the information systems that we had been managing with pencil and paper within a series of computer programs.

This process in and of itself has proved to be time consuming and difficult. The system was supposed to be delivered in February but problems both at Chrysler and Royal have delayed this delivery date until May But, once the TTM pilot is successfully converted over to a computerized operation it will be much easier to expand the system to other departments. Also, the development time and expense required to develop the computer system will not be replicated for each department that TTM is installed in. The computer system we will use to manage the TTM pilot can be cloned to handle other department's requirements.

The Royal software for TTM, built within a Paradox database, essentially replaces all of the paper used to track tool performance and to create tool change schedules. Using computer terminals in both the job setter crib and the cutter grind department, wear measurements and unscheduled tool changes will be entered into the system by floor personnel. The system will create daily tool change schedules for the job setter and will track tool consumption and inventories. Successive versions of the software will contain algorithms that can search for potential tool problems using heuristics which mimic the problem solving methodology employed by the TTM team.

While the final architecture of the Royal system is not yet set, our goal is to align the software system's characteristics with those of the paper system now in place. The development of this information system is a major endeavor which consumes large amounts of human and financial resources. Our recommendation to others developing a tool management system is to first develop the system independent of any formalized computer system. If the system can operate in a paper mode and provide tangible benefits then cost over-runs and missed deadlines during the development of the computerized version will be less painful.

7.3 Plans for Expansion Throughout Trenton Engine Plant

As of December 1992, the plan for expanding TTM throughout Trenton consisted of three phases. Figure 7-1 outlines the three phases and their respective time frames.

To date progress has proceeded in fits and starts along these lines. Implementation in the 3.5L head line has proceeded, and implementation in the 3.3L block line has stalled after an encouraging start. The difficulties in the 3.3L block line are due in part to the culture of the department and the difficult nature of the machining processes there

TTM Blueprint for the Future

Phase I: Implement 3.5L Head Line and 3.3L Block Line

- Form initial tool management team
- Complete installation in 3.3L block line
- Begin development of 3.5L connecting rod program
- Completion Date: June 1993

Phase II: Implement Tool Management in 2.0L Departments

- Develop additional tool management implementation teams
- Begin reconfiguration for cutter grind department
- Lay ground work for job setter centralization
- Completion Date: December 1993

Phase III: Expand Tool Management Throughout the Plant

- Parallel development by several teams
- Implement resource sharing and centralization
- Complete Cutter Grind Restructuring
- Completion Date: January 1995

Figure 7-1: Proposed phase-in for Trenton Tool Management, December 1992.

But, more global factors have threatened to derail the 3.3L implementation process as well as to undermine the implementation of TTM in the new 2.0L departments.

TEP is presently in the process of a major reorganization. Previously, the plant was roughly organized into production and non-production elements. Each manufacturing department manager reported to the Production Manager who reported directly to the plant manager. Support departments, like cutter grind, tool engineering, maintenance, etc., fell under the Manufacturing Engineering (ME) manager. The ME manager also reported directly to the plant manager. Under the current reorganization the plant is divided into several "mini-plants", each with its own production manager. Within the mini-plants each department manager reports to the production manager for that portion of the plant. These mini-plant production managers then report to a global production manager, who in turn reports to the plant manager.

Under this new system, responsibility for the various support departments is to be divided among the production managers for the mini-plants. And, some of the support departments, like tool engineering, may be disbanded, with individual tool engineers reporting within the mini-plant structure. In addition there have been significant personnel changes in the upper management ranks. The uncertainty surrounding this shift in structure, and uncertainty as to who will be responsible for the tool management program, has delayed advances in TTM. The TTM team is currently working with management to sort out how the TTM program should continue. it is important that sufficient man-power continue to be allocated to its development.

8.0 Summary and Conclusions

For this project we developed and piloted a new tool management system for use in a mass production metal working facility. This new tool management system, dubbed Trenton Tool Management (TTM), was designed to address the following problems presently found at the engine plant:

1. High levels of tooling consumption
2. High levels of tool inventory
3. Low tool quality

In addressing these problems TTM also contributed to the manufacture of higher quality parts at a lower cost than could be achieved using conventional tool management practices. Thus, the overarching goal of this project was to design and pilot a tool management system which would reduce costs and drive the continuous improvement of production quality and volumes.

These goals were achieved by creating a system of tool management that focused on improved control and management of the physical tooling, and provided high quality information about tool performance.

We Faced Two Significant Challenges

But, while the design of TTM was important, the greatest challenges we faced concerned the implementation of the TTM pilot in the 3.5L V-6 cylinder head machining department. Whereas the design of a new manufacturing system can be achieved through the efforts of a handful of people, the implementation of a new process or manufacturing system relies upon the coordinated action of dozens, if not hundreds, of plant personnel. This has led us to conclude that the critical element in bringing about improvements in the mass production environment is not the design of improved manufacturing processes, but rather the design of the manufacturing organization itself.

Under the present organizational structure at TEP, and most Big Three plants, the "thinkers" are placed at the top and the "brawn" is placed at the bottom of the organizational hierarchy. Innovations are devised at the higher levels of the hierarchy, often far removed from the realities of the manufacturing floor. These innovations then trickle down the organization to the factory floor where they are implemented. Because of the discontinuities between the design of an innovation and its implementation, in terms of both people and time, optimal results are rarely realized.

In developing TTM we tried to integrate personnel from all areas of the plant into the design process. This was a difficult task. Many factory floor personnel did not want to be involved with the project, and as a result did not readily contribute their expertise to the design of TTM. Others felt threatened by TTM and worked to undermine its evolution. But, as we worked with people from all levels in the plant, and began to integrate their suggestions and respond to their concerns, attitudes changed. Locally, we were able to change the organizational hierarchy as it related to tool management. Job setters, cutter grinders, tool engineers, and supervisors began working as peers, and the demarcations of rank that pervade factory life became much less clear. As a result ideas were exchanged more freely, and workers took on additional responsibilities to insure that TTM would succeed.

In addition to the challenge of grappling with a hierarchical organization, and all that it implies regarding working relationships within the plant, the TTM pilot uncovered a weakness which represents the greatest long-term challenge to TEP, and mass production systems as a whole.

This weakness is best illustrated by way of an extended analogy. A used truck I once owned had an exhaust leak which created a lot of noise as I drove down the road. For lack of money I left the exhaust in this state for about three months. Eventually, I brought it into the shop to have the exhaust replaced, expecting that afterwards the truck would run quietly. When I left the shop I was shocked to hear another noise, a loud clanging, which appeared to be coming from the transmission. As it turned out one of the bolt holes on my fly wheel had become elongated and the flywheel was perilously loose, a much more serious condition than the exhaust leak which had masked this problem to begin with. In developing TTM we encountered a similar situation. We perceived the management of tooling to be a root cause of high manufacturing expense and attacked this problem enthusiastically. By implementing our solution we discovered a more fundamental problem. Many of the skills required to make TTM a tenable improvement were not widely available throughout the plant. While we were largely able to circumvent the issue of skill deficiencies during the pilot by selecting the employees who worked on the pilot, the issue of skill deficiencies must be addressed if TTM is to be expanded throughout TEP.

The skill deficiencies we encountered ranged from illiteracy, to the inability to solve simple math and logic problems, to a lack of organizational and computer skills. Historically, mass production systems mask these deficiencies. One could argue that they have also helped to create them. Mass production jobs, at all levels of the plant hierarchy, emphasize the performance of rote tasks rather than an ability to rapidly respond to the new or unexpected. As a result, an inability to read, or understand basic SPC concepts for example, is not debilitating within the mass production environment.

Our current way of thinking tells us that workers can be *trained* to use SPC charts. Today, as competitive pressures increase, we must *educate*, not train, our workers to use SPC charts. As practiced in mass production facilities, training is the teaching of a very specific skill or task. Training takes a narrow view of its subject, focusing on the details of the task. Education, on the other hand, teaches skills within a broader context, and the skill itself is not so much the focus as are the general principles underlying that skill or task. I am convinced that recognizing the distinction between training and education, and working to integrate the former into the latter is the single biggest challenge facing manufacturing at Chrysler today. As the rate of change in manufacturing processes and products increases, training becomes less and less valuable. By the time the worker has become proficient at a skill through training, that skill may be obsolete. The key is to educate workers in such a way that they perform at a high level *and* adapt to new manufacturing systems and processes.

With this in mind we made a conscious attempt throughout the TTM pilot to educate workers about the enabling concepts behind TTM (e.g. - the use of feedback for process improvement, the role of inventories, the concept of visual control, JIT concepts, etc.) rather than training them solely in the procedures required to perform TTM. While we were not completely successful in these efforts we feel that great strides were made towards making TTM a vehicle for continual improvement, rather than a one time step-wise improvement in plant performance.

To conclude, beyond the benefits provided by TTM, this project led us to identify two areas where fundamental changes could greatly improve plant performance. The first is the organizational structure typically employed in a mass production facility. Only by creating an environment where everyone's ideas are valued and solicited can the improvements demanded of our factories be achieved. Second, a great effort is required to improve the skill base of the plant workers. While measuring the financial pay back from education is a difficult task we must avoid the conclusion that because it can not be readily quantified it has no value. A massive, well orchestrated effort to improve the ability of TEP's workers to adapt to the readily changing environment in which they work is required if the plant is to remain competitive in the years ahead.

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Appendix A: Problems Perceived in Current Tool Management at Trenton Engine Plant

The following is a brief list of the problems inherent in current methods for managing tooling at Chrysler's Trenton Engine Plant. The information presented was compiled through discussions with managers, and workers, and through direct observations.

Problem Area: Production Departments

1. Tools break unexpectedly
2. Production is lost due to tool changes
3. The cause of tooling problems is difficult to identify
4. Problem solving techniques are not rigorous or systematic
5. Required tools not always available from tool cribs
6. Worn tools are used in machinery
7. Production personnel horde tools, increasing tool inventories and costs
8. Poor communication with Tool Engineering
9. Tool change frequencies are not continually optimized
10. Initial tool change frequency values are inaccurate
11. Volume of tooling on the floor is unknown

Problem Area: Tool Crib

1. Tools are not sent to cutter grind for regrinding in a systematic, or optimal, manner
2. Scrapped tooling is replaced in the float without question
3. Tools are separated by department, even if the tool is common between them
4. Tools enter the retail crib from wholesale whenever a tool is scrapped, even if inventory in retail crib is adequate

Problem Area: Cutter Grind

1. Grinding of tools only loosely linked to demand
2. Minimal tool inspection, no documentation
3. Tools ground in lots of arbitrary size
4. No formal reporting of scrapped tools or diagnosis of problem
5. Key tool dimensions not easily accessible
6. No data available to upgrade regrind estimates, tool life estimate

Problem Area: Tool Engineering

1. Interactions between APTME and TEP regarding the development of tooling and tool life estimates are uncoordinated
2. Operation sheets are not standardized. Different engineers use different sheets
3. Little historical information available to aid tool selection, usage optimization
4. Communication between engineers and production personnel on a "need to know basis"
5. Besides fire fighting, tool engineers do not have the information or resources to identify those areas that represent the greatest potential for cost savings and profit generation

Over-arching Problems

1. Costs, beyond actual purchase costs to operate and maintain tooling, are unknown
2. No process for generating continual cost reductions and performance improvements is in place. At present, improvements come on a project by project basis, where each project is conceptualized and implemented independently

Appendix B: DM/TBI Policy

The following memo outlines the DM/TBI policy developed as part of the TTM pilot.

To:	Department Managers
From:	See below
Subject:	Procedures to obtain tooling (DM/TBI Policy)
Date:	November 9, 1992

To facilitate the better management of the tooling used in the plant, and to prevent defective material from getting into machine tools, the staff of the tool crib and tool engineering has come up with the following procedure. The goal of this policy is to insure that tool inventories are kept under control and that tool costs can be tracked, and reduced. When followed, this policy will enable the plant to run more smoothly and will not increase the time required to acquire tools and other material in the event of an emergency. This policy is necessary to ensure that orders for tools are placed as required and will help to prevent tool shortages.

This procedure is to be followed exclusively; orders given to tool crib, cutter grind, or other personnel which contradict this policy will not be carried out!

This policy is to be enforced by those whose names appear at the end of this document. Please direct any questions regarding this policy to the below mentioned personnel, Joe Martin (Dept. 34 TC) at x4208, or Walter Durandetto and Miles Arnone at x4153.

Regarding TBI and DM

1. No material is to be removed from tool and gauge inspection under any circumstances.

2. All tools must be dispersed through the crib (Dept. 34) using the badge/credit card system. Plans are being put together to put a door between tool/gauge inspection and the secure crib in the tool crib to facilitate the movement of tools between these two areas.

3. If material is required prior to inspection (TBI) it will be sent to the tool crib and logged on a "TBI Log" before being disbursed. This log will be maintained by the tool crib and will be distributed weekly to Bill Mulhern, Jack Arnest, and Frank Monaco.

4. An area manager, or tool engineer, must sign out TBI material on the "TBI Log" at tool stores prior to receipt of the material. Excess material, beyond that required immediately for the emergency condition, is not to be given out under any circumstances.

5. DM material can be obtained from Department 34 only by an area manager, or tool engineer, who signs out the material on the "DM Log". This log will be maintained by tool stores and will be distributed weekly to the aforementioned personnel. Excess

materials, beyond those required for immediate alleviation of an emergency condition will not be distributed.

Regarding Tooling and Cutter Grind (Department 0350)

1. No material is to enter or exit Department 0350 except through the tool crib.

2. In the event of an emergency (machine down, etc.) the tool crib will write a ticket for the tools that require grinding and the tools can be "walked through" cutter grind by the person that requires them.

3. Before "hot" tools can be released from cutter grind they must be checked-in at the tool crib. No tools will be released from cutter grind to the floor directly before the proper paperwork is brought to the tool crib.

Regarding the Purchase and Delivery of Tooling and other Items

1. All vendor items are to enter the plant through Door 9.

2. Plant protection will not accept material.

3. Vendors will not bring items directly to the floor, except test items for which Chrysler is not paying (e.g. - test tools).

This policy is fully supported and will be upheld by those whose signatures appear below.

Jim DeKeyser, Plant Manager
Terry Davis, Production Manager
John Lycett, Operations Manager
Bill Martin, Area Manager
Steve Lankford, ME Manager
Joe Tucker, Production Control Manager
Frank Monaco, Tool Services Supervisor
Bill Mulhern, Tool Engr. Supervisor
Jack Arnest, Gage Inspection

Appendix C: Example of Continuous Improvement Using Trenton Tool Management

Spindle Failure Identification Memo #1

To: Larry Deszell
From: Miles Arnone, Walter Durandetto
Subject: 524 Tool Management Program
Date: September 1, 1992

The tool management program has been in full swing for about two weeks now. Here are some notes on our progress and problems we are facing.

Four tool changes have occurred
All tools with tool change frequencies of 2500 pieces in operations 20R, 30R, 40R, 50R, 60R, and 70R have been changed. It appears that Reese [*second shift job setter*] will easily be able to handle the amount of tools that need to be changed in a given evening.

Tool stores has carted the tools back and forth from the department without incident, although they have complained about the table being blocked off on several occasions.

The cutter grinders, particularly Bill and Dale, have been very helpful. Tools have been inspected for wear and reground very quickly. Most tools are inspected and reground within 24 hours. This has allowed us to keep the float [*inventory*] in the 524 crib down to two sets of tools (plus one more in the machine).

We have also been able to increase the tool change frequencies on all 2500 piece tools in OPS 20R, 30R, and 40R to 3000 pieces. Even higher tool change frequencies are expected for most of these tools. The tools from 50R, 60R, and 70R are being checked for wear now. Some of these tools appear to be heavily worn after less than 3000 pieces. We will update you when Dale completes his review of the tools.

Movement of the 524 Crib
We think that despite the difficulty in bringing tools back and forth between the crib and the transfer line when breakages occur, that this move has been successful. John can interact with cutter grind and tool stores more easily and they have been able to work out many tooling related problems quickly and efficiently, particularly with regards to wrong tool numbers, and improperly sized tools.

A Tooling Problem
As we had talked about earlier, one advantage of the program is that it can identify recurring problems that may not be tool related, but that cause tool breakage. <u>OP20A, ST13RH, Spindle #131 may have a spindle problem</u>. The tooling used in that spindle has broken three times at less than 1000 pieces. Yet, the same type of tooling, used in

spindles #127, #128, #129, #130, and #132 has had only two breakages between all of those spindles (one each on #130, and #132). Since these breakages on #130 and #132, almost 1000 pieces have been made with the replacement tools without incident. On spindles #128, and #129 almost 2800 pieces have been made without any tool failures.

Charlie Rice, of the Vibration Analysis Lab, is going to take a look at the spindle. Normally, you or the department tool engineer would decide to take such steps, but we happened to bump into Charlie and mentioned it to him.

Future Schedule
No tool changes are required this evening. Some tool changes will be required in Operation 20A tomorrow evening.

Spindle Failure Identification Memo #2

To:	Larry Deszell
From:	Miles Arnone, Walter Durandetto
Subject:	524 Tool Management Program
Date:	September 2, 1992

Tooling Problems on OP20A ST13RH Spindle #131
Another tool broke on this spindle today, making it more likely in our opinion that the problem is a spindle problem rather than a tooling problem. This brings the total breakages on that spindle to four (vs. 2 breakages of the same tool # on all other spindles combined).

The vibration analysis of the spindle indicates that the bearings are running "freer", indicating a loss of pre-load. This may be the cause of the problems due to increased chatter, or chipping of the tool due to rotation of the spindle off of its center line. While this is only an educated guess, it is something worth looking into.

Tool Change Frequency Update
The attached sheets show the recommendations for tool life frequencies for tools that were changed on OPs 50R, 60R, and 70R. These sheets have been passed on to Dave Sedliar for his approval. While the tool lives for most tools are still on the rise you will see that some have leveled out. T-52 and T-54 are peaked on life at about 3000 pieces.