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CASE STUDY: TOOL MANAGEMENT AT GENERAL MOTORS POWERTRAIN WILLOW RUN PLANT

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ABSTRACT

This paper details important tool management issues for a particular facility, the General Motors Powertrain (GMPT) Willow Run Transmission plant. The Willow Run plant manufactures a variety of transmission components and assemblies. Elements and shortcomings of the existing system are discussed. Then an appropriate tool management system is prescribed to improve the current situation. The system had to be designed to work within the Powertrain organizational structure and to comply with management dictates. Implementation issues are discussed. We also provide future tool management enhancements that could be implemented if the currently required organizational constraints could be relaxed.

The paper describes the benefits of managing cutting tools, and its effect on the bottom line. The primary focus is on the elements of tool management at the manufacturing shop floor level. While an optimal tool management system should incorporate many functions (stores/cribs, purchasing, process engineering, production planning, and cutter grind, for example), we primarily focus on the substantial increases in throughput and reductions of tooling cost that can be realized by sound tool management at the shop floor level. The focus is on systems that can work within the existing organizational structure.

This paper is not only an engineering case study, but aims to enlighten plant management about the financial and operational merits of sound tool management. The tool management improvement policies are generalizable. Additionally, this study reflects the actual operating conditions of GMPT and is not a comprehensive tool management system for any job shop type manufacturer, which would have differing scheduling and changeover requirements. Concepts discussed are readily applicable to most manufacturing facilities of GMPT's nature.

Key words: Tool management, case study

1. THE GENERAL MOTORS POWERTRAIN WILLOW RUN TRANSMISSION PLANT

This paper describes recent tool management improvements at General Motors Powertrain (GMPT) Willow Run Facility, in Ypsilanti, Michigan. The description of both the plant and the 4T80E product line is presented in section 1. The roles of various manufacturing support functions involved in tool management are described. The primary constraints to a tool management system design are provided.

Section 2 describes the current state of tool management at the GMPT Ypsilanti plant. Section 3 defines tool management elements and objectives. Section 4 details the proposed initial tool management system to accommodate the GMPT Ypsilanti facility subject to the imposed constraints. Also, the elements required in managing and implementing the system are discussed. Section 5 outlines the relevant lessons learned in both implementing and maintaining an integrated tool management system. Finally, Section 6 describes further tool management enhancements that are available when the currently required plant constraints can be relaxed.

1.1 Plant Overview

General Motors Powertrain is a manufacturer of automatic transmissions and transmission components. It assembles four models internally and supplies components to three other transmission assembly plants. The facility is about one mile long by one quarter mile wide and employs over six thousand employees. Willow Run has content on all GM domestic automatic transmissions with the exception of Saturn. Production is organized into various autonomous product lines designated by the transmission model produced. As of mid-1995, transmission models are as follows:

<u>3T40</u> - Manufacture and assembly of small front wheel drive transmissions. Volume is 2,500 transmissions per day. The 3T40 has been in production since 1978.

<u>4T40E</u> - Manufacture gears and shafts for a front wheel drive transmission manufactured at another facility. 4T40E began production in 1994 and is currently ramping-up to replace the 3T40. Eventually, component production will supply 4,000 transmissions per day.

<u>4T60E</u> - Manufacture components such as clutch housing assemblies for a mid-size front wheel drive transmission produced at another GM facility. 4T60E also produces stampings, valves, and bushings for all Powertrain-produced transmissions. Production

began in 1985 and volume is 6,900 transmissions per day.

4L80E - Manufacture components and final assemblies for a rear wheel drive transmission used primarily in large trucks. Volume is 1,200 per day. The transmission has been in production since 1991.

3L80 - Manufacture components and assemblies for the predecessor of the 4L80E. Production began in 1964 and volume is approximately 50 transmissions a day.

4T80E - Manufacture components and assemblies for a front wheel drive transmission used in high performance luxury vehicles (i.e., Cadillac). The transmission has been in production since 1992 and volume was recently 600 transmissions per day. In July 1996, volume was 1,100 per day.

Although all product lines are within the plant, they are autonomous, each having their own production management. Each department manufactures to a fixed schedule with dedicated machinery (for each manufactured component) utilizing a focused factory layout. The only exceptions to fixed volume manufacturing are some gear and sprocket departments that change over to accommodate different transmission output ratios. Stamping, valve, and bushing production run in batches to minimize impact of changeovers.

1.2 The 4T80E Product Line

When this project started, the 4T80E group, with a relatively small volume of 600 transmissions per day, constituted approximately 25% of tooling costs in the Willow Run facility ($18,000 per day). This is because of the content of its gears manufactured in the facility. The product line is separated into departments. each producing one component or component family type. See Table 1 in the Appendix for a breakdown of the manufacturing equipment used on the 4T80E product line. Tools used on this product line have one or more of the following characteristics:

- tools requiring special set-up;
- PCD reamers and inserts;
- re-sharpenable tooling;
- disposable tooling;
- broaches and shaping tools;
- tooling requiring sharpening by outside suppliers;
- tools used on flexible equipment (capable of easy model changeover, etc.);
- repairable tools.

There is only one department in the product line required to run varying schedules with changeover and model mix. This department manufactures pinions and sun gears for final drive assemblies in three different ratios. The mix is driven by the varying demand of final assemblies and in-process float. Although tooling can be readily changed on flexible hob and shave equipment, there are special considerations and unique problems associated with managing tools for equipment frequently changed over. These problems and considerations are discussed in detail in Section 4.8.

1.3 Tool Management Support Functions

Tool management at the plant level primarily concerns five functional groups: Manufacturing, Cutter Grind, General Stores and Cribs, Purchasing, and Process Engineering. This subsection describes how these organizations interact at the Willow Run facility.

Manufacturing. Production is responsible for the tooling budget performance. Other tool-related responsibilities include tool change, machine utilization, and equipment upkeep. Machine set-up is the responsibility of the job setter and tool change is shared by the job setter and machine operator depending on equipment type. Other job setter responsibilities include working with process engineering and maintenance regarding tooling-related problems. A tool chaser is responsible for providing new tooling to the manufacturing departments and returning dull tools for refurbishment. The tool chaser is considered to be the liaison from manufacturing to cutter grind and the crib system.

Cutter Grind. Cutter Grind is an internal organization composed of skilled craftsman responsible for the resharpening of cutting tools. Cutter Grind has plant-wide responsibilities for sharpening all cutters. This includes drills, broaches, shavers, hobs, shapers, and reamers. Other responsibilities include set-ups for indexible mill cutters and special boring tooling. The only significant cutter style that Cutter Grind does not have the capability to sharpen is poly-crystalline diamond tooling. These cutters are sent out to outside suppliers for refurbishment. Cutter Grind does not work to any particular schedule and usually prioritizes based on interaction with the tool chaser or historical use as determined by the grinder personnel and/or supervision.

General Stores and Cribs. Manufacturing purchases new tooling through the crib system (in the internal warehouse where indirect materials are stored). Each disbursement is entered into a computer which automatically tracks tool usage and generates a "purchase authorization" when tooling has reached a reorder point (based on historical use and manufacturing lead-time). This system is maintained by General Stores, whose responsibility is to examine the purchase authorization and adjust the order quantities in response to special circumstances (if any). The General Stores supervisor is responsible for controlling the cost of new tool purchases by releasing orders based on a $60,000 daily budget.

Purchasing. Purchasing acts upon released purchase authorizations in two manners. Either the order is sent out for bid, or if a blanket order is set-up, they send the order directly to a supplier. Blanket orders generally take 1-4 weeks for processing, while orders sent for bid take from 4 to 12 weeks. Purchasing is generally perceived by production personnel to purchase on a price-only criteria. The consequence is that tooling received is often of lesser quality than if purchased from more reputable suppliers.

Process Engineering. Process Engineering specifies all machines and tooling used by production. They are also responsible for resolving on-going tooling problems and initiating continuous improvement.

1.4 System Constraints

To develop and implement a tool management program, several organizational and operational constraints had to be considered at the Willow Run plant. These include the following:

- Only those manufacturing aspects of tool management that can be implemented at the shop floor level could be addressed;
- Cutter grind scheduling problems could not yet be addressed. We could focus on developing a feedback loop regarding quality;
- The purchasing procurement processes could not be changed. We could collect data which is mutually beneficial to both purchasing and manufacturing;
- Any tool management improvements had to be designed to work within the general stores reorder and stocking system.
- The tool management system could not be susceptible to rotations of employees due to layoffs, etc.;
- No additional head count could be added to accommodate a proposed tool management program.

Our objective was to smooth 4T80E tool usage and resolve many manufacturing problems associated with poor tool management. These efforts should, in turn, improve the performance of the tooling support groups. Once tooling problems are resolved on the floor, shortcomings in the supporting groups will become apparent and can then be addressed.

2. THE CURRENT STATE OF TOOL MANAGEMENT AT THE WILLOW RUN PLANT

This section describes the current tool management conditions at the Willow Run Plant and within the 4T80E product line. Current tool management components are evaluated and critiqued.

2.1 Existing Tool Management for All Product Lines

Because of the product line structure of the plant, Willow Run does not have a consistent tool management strategy. While elements of tool management exist throughout all product lines, there is no comprehensive system. Four factors contribute to the lack of plant-wide tool management:

1. There are different managers and philosophies for each product line and a lack of communication regarding best practices.

2. The age and volumes of manufacturing equipment and the composition of transmission assemblies vary on product lines.
3. There is a lack of ownership for the fundamental tool management elements (i.e., stores, cutter grind, production).
4. Accounting and performance measures for tool management are not adequate.

Cutter Grind has been considered the owner of plant-wide tool management. However, because of their limited control over production, they had not been able to grasp some fundamental issues associated with tool change.

The only significant tool management procedure in the plant is on the 3T40 product line, which utilizes the CATCAMS program (written by EDS), a software system that generates tool change schedules. CATCAMS uses recommended tool lives and production part counts to generate a daily tool change schedule. Because tool change lists are generated only once each day, the program cannot easily be used for tools that require changing several times per day; it is limited to tools capable of running several days. These are for primarily aluminum machining operations. Although the program is successful in its limited applications, we suggest to not use it on our product line for the following reasons:

- Since the CATCAMS schedule is generated daily. it cannot be used on tooling with shorter lives. A high proportion of 4T80E processes require tool changes more than once per day:
- The system is cumbersome. requiring the part counts, and scheduled and unscheduled tool changes. to be entered into the data base daily for all production equipment;
- Utilizing CATCAMS would require additional head count that would neither be available nor allowed.

2.2 Existing Tool Management on the 4T80E Product Line

Elements of tool management also exist on the 4T80E product line. Listed below are the predominate methods and aids used on this product line:

- *Fanuc tool management* - A canned program is available on Fanuc controllers that counts cycles for each tool and then notifies the operator when a tool change is required. The program also has the option of indexing to a fresh tool after a designated cycle count;
- *Macros* - Macros are subroutines written for Fanuc controllers that count tool cycles. They are equivalent in function to Fanuc tool management but not as user friendly;
- *Tool change logs* - These are manually kept logs (generally contained in three ring binders) used to keep track of tool changes;

- *Dry-erase marker boards* - Operators keep track of the cutting cycles of their tooling by noting desired tool change timing on dry-erase marker boards that are mounted on the machines;
- *Allen-Bradley* - Tool change programs (similar to the Fanuc) are written for some Allen Bradley controllers.
- *Statistical Process Control (SPC) charts* - Standard SPC charts are used to monitor tool-dependent characteristics and to help determine when a tool change is due;
- *Broken tool detectors* - Some applications use tool wear detectors to monitor dull or broken tooling and to then designate tool change times;
- *Tool boards* - Tool boards are available for most transfer or dial equipment. The term "tool boards," for discussion purposes in the remainder of the paper, describes any means for displaying preset tools in a manner in which they can be visually checked for availability.

Most of these elements were either specified on original equipment purchases or were developed by or requested from floor personnel. Unfortunately, they are very limited in scope - mostly focusing on tool change - and are limited to only about 10% of the manufacturing equipment. Shortcomings of the current 4T80E tool management include:

- The amount of equipment having formal tool change procedures is very limited;
- The product line lacks a uniform direction with a known set of objectives;
- Existing methods are not documented and therefore not auditable for compliance;
- All elements of tool management are not addressed;
- No set of tool change specifications exists.

2.3 Current Problems

The following are some frequent tooling problems encountered by the 4T80E product line:

Cutter Regrinds. Reground cutters often continued to have problems without a resolution. The following is an example of a typical regrind problem:

> *A special mill cutter continued to have problems after resharpening. The problems were so consistent that the operator refused to use anything but new cutters. Total new cutter use at this operation is about 710 per year at $42.00 each (about $30,000.00 annually). If these cutters were to receive the specified 10 grinds per cutter, new tool purchases would be reduced to only $3,000.00 a year.*

The root of these problems is probably not because of cutter grind talent, but because of the lack of a system to provide feedback and proper documentation to the cutter grind operators.

Regrind Scheduling. If there is no operator to see that a particular tool is ground in a timely manner, it may sit in cutter grind for a long time with production continuing to use new tooling from the cribs. Tool grinding is scheduled by two means: pleas from production or historical usage (for high volume cutters only). There is no formal schedule. Low volume tooling is particularly affected.

Cutter Designs. Poor cutter and set-up designs cause downtime and production problems. The following case illustrates one such design problem:

In a gear cutting department, hobs are set up on arbors before being placed in the machine. Poor design of these cutters makes it difficult to adjust the run-out to proper levels. Run-out is a characteristic of hob set-ups that is critical to machining gears to the proper specifications. A further complication is that there is no run-out parameter specified to set-up personnel for the adjustment of these cutters. Frequently, a new cutter is installed in a machine and then the initial cut parts are measured out-of-specification. Immediately, the cutter assembly is taken out of the machine, and a new hob assembly is put in the machine. The result is that the hob is misdiagnosed as bad and reground, when actually a poor set-up is the problem. This particular case can be addressed by making the arbor an integral part of the hob which then eliminates the need for set-up. Many other similar problems exist in the product line.

Tooling Shortages. Shortages of tools occur on a daily basis. Expediting tools or making special alterations to sustain operations takes time that could otherwise be used for proactive measures. It is not uncommon to ship tooling on commercial airlines or with special expediting services. Systems should be in place that would allow such shortage problems to be detected before extreme measures become necessary.

Tool Change. In many operations, tools rarely get changed until they break or parts measure out of specification limits. In other applications, tools will get changed prematurely. Premature tool change occurs because there is no formal tool change tracking system, so operators change tools at the beginning of a shift, rather than after a specified number of cycles.

Purchasing. The purchasing process can take up to 15 weeks in some cases. Each "purchase authorization" computer-generated quantity is based on an algorithm that was designed to prevent stock-out, yet also maintain minimum crib requirements. Not acting immediately on a purchase authorization also increases the probability of stock-outs.

Poor Supplier Quality. Supplier quality is generally perceived as poor, but a lack of a tracking system has left production powerless in addressing these concerns. Purchasing ignores undocumented production pleas, and continues to purchase from troublesome (but cheaper) suppliers. Often, critical parts such as collets have to be altered to be assembled on a machine. Most of the time, these parts get altered in-house (at General Motors' expense) due to lack of backups necessary for sustaining production.

Reaction to Potential Tool Shortages. Equipment malfunctions may generate excessive tool usage. When this occurs, General Stores are generally not notified until the lack of sufficient tooling has reached a critical level.

Tool Change Time. Most tool set-ups occur during productive time while a machine sits idle. While tool boards and preset areas are often available, they are generally not sufficiently maintained and stocked. Off-shift tool change is not systematically used.

Broken Tools. In some operations, expensive finishing tools break as a result of mis-clamped parts or broken or worn roughing tools. The following example illustrates the potential cost:

In one particular case, a non-perishable Mapal finishing tool ($2,500.00 each) was damaged after the failure of a $200.00 rougher. In one year, the total expense of this non-perishable tool was $72,000.00. In this application, broken tool detection methods should have prevented all of these failures.

Measuring/Gauging Systems. In one particular inspection case, M&M gear measuring equipment has approximately 50% of the gauging resolution that the part print tolerances require. With a large amount of variation, premature tool changes occur and machine capability is underestimated.

Tool Hoarding. Some tool hoarding by both machine operators and job setters occurs as their means to buffer against deficiencies in the system. In addition to causing inventory and cost problems, hoarding can cause quality problems: there could be quality defects from an operator running an old (hoarded) version of a tool.

2.4 Problems in the Tool Management System

The existing systems discussed in Sections 2.1 and 2.2 only address particular tool change issues, not the entire spectrum of tool management. Additionally, these existing efforts are only sporadic, and do not address an entire product line. To date, no boundaries have been defined about tool management responsibilities between production and their support groups. There is little coordination of tool management efforts, and therefore no tool management consistency, either plant-wide or even within product lines. A successful tool management program should be well documented, and therefore controllable and auditable.

At Willow Run, there has been a tendency to work on the "problem of the day," while little focus is directed at addressing the root causes of the problems. A proper tool management system should be designed to help as a catalyst for significant behavioral change. Willow Run needs to become proactive to tooling needs and problems. As one manager mentions: "we used to kick heads, now we chart characteristics, understand our process, and try to react appropriately." While kicking heads here refers to the process of adjusting Fellows gear shapers (kicking heads with data), kicking heads of suppliers, General Stores, or production personnel does not resolve long term problems. Careful, organized, consistent planning does.

3. FUNDAMENTALS OF TOOL MANAGEMENT

Broadly, the goal and benefits of tool management are reducing production costs, improving quality, and increasing throughput by managing cutting tools. Tool management, from an organizational perspective, should focus on a broad range of issues including:

- *vendor relations (partnerships):* lower inventory, "low price is not low cost," quality, innovative delivery, and tooling inventory management;
- *cutter grind:* delivery, resource utilization, scheduling, and quality;

- *cost of quality:* bad quality results from broken or worn tools;
- *production tool control:* tool change programs, resolving tooling problems, utilization of reground and repaired tooling, optimizing up-time (presetting of tooling, etc.), and process control.

Good tool management is often summarized as having the right tool in the right place at the right time in the right condition at the right cost. As Ranky [18] notes, proper function of a tool management infrastructure is dependant upon correct tooling information.

3.1 Why Tool Management

Tool management is necessary for improving the bottom line. The results of tool management impact machine utilization, overtime, scrap, indirect material inventory, quality, and total tool cost. Jones [13] notes that, "Effective tool management can make a major impact on the productivity and profitability of a metal working operation. Recent studies show an effectively implemented plan can increase machine cutting time as much as 50% and reduce tooling inventories by up to 40% " Tooling has been estimated to account for 25% to 30% of the cost of production (Cumings [5]). Gray et al. [8] note that a lack of attention to structured tool management has resulted in a poor performance from many manufacturing systems. The following are key goals and benefits from managing tools on the production floor:

Maximize tool life. Understanding tooling costs and cycle times identifies opportunities to increase tool life through re-engineering or optimization.

Maximize cutter regrinds. Many cutters have the ability to be re-sharpened by grinding. Maximizing the number of regrinds per cutter and the efficiency with which it is returned to production substantially reduces the frequency that virgin tooling is pulled from a crib. This reduces the amount of tooling purchased on an annual basis and the average amount of new inventory on hand. Table 2 and Figure 1 show the cost benefits of regrinding for a particular example of a cutter that has to be changed at a rate of 10 cutters per week. As shown in Table 2, the annual tooling purchases can decrease by 40% with just one regrind per cutter and over 73% with 10 regrinds per cutter. This example assumes that it costs 20% of the original value to resharpen a tool.

Reduce stock-outs of cutting tools. Eliminating unnecessary tool breakage and maximizing cutter regrinds smooth cutting tool use. This is compatible with General Stores continuous review inventory management. With more uniform tool consumption, General Stores is able to maintain smaller inventories due to more predictable reorder points.

Reduce downtime. Efforts should focus on minimizing downtime for required tool changes. Elements to consider are the timeliness of tool change (i.e., off-shifts, operator breaks, etc.) and speed in which the tool change occurs.

Table 2. Tooling Costs as a Function of Regrinds per Cutter.

Regrinds/ Tool	Tool Cost	Tool Use/ Week	Cost of Regrind	Annual Tooling Costs
0	$500	10	$100	$260,000
1	$500	10	$100	$156,000
2	$500	10	$100	$121,333
3	$500	10	$100	$104,000
4	$500	10	$100	$93,600
5	$500	10	$100	$86,667
6	$500	10	$100	$81,714
7	$500	10	$100	$78,000
8	$500	10	$100	$75,111
9	$500	10	$100	$72,800
10	$500	10	$100	$70,909

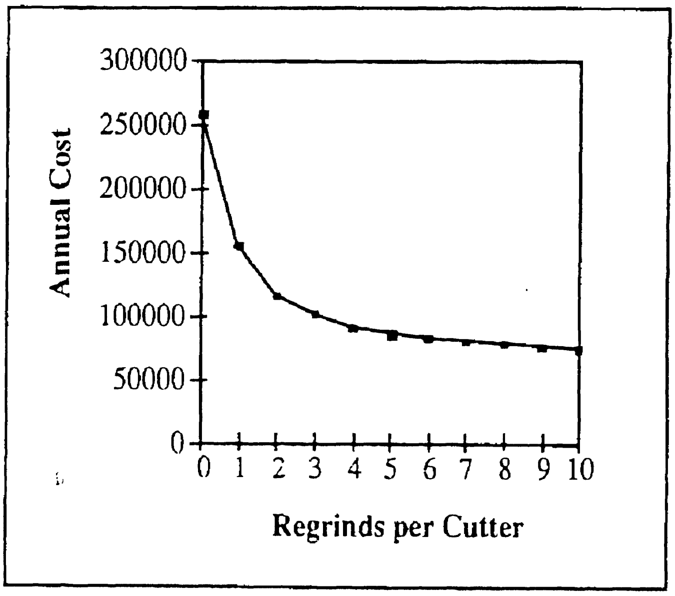


Figure 1. Graph of the Annual Tooling Costs of Table 2.

Resolve tooling problems/vendor issues. Costs of defective tooling can be measured in terms of machine downtime, scrap, and the cost of altering defective tooling. Tool management should track problems and resolve them by determining the root causes and addressing them with permanent documented fixes, thereby reducing the probability of reoccurrence. When certain vendors have continuous quality problems, data should be readily available to make a case for the removal of problematic vendors from the supplier base.

Reduce tool breakage. Sound tool change procedures reduce the risk of tool breakage. This decreases the use of new cutters by assuring that in-process cutters receive the maximum number of regrinds. Improving the utilization of cutters reduces the chance of tooling stock-out, or the need to carry additional tooling inventory as a hedge against tool use fluctuations occurring from unexpected breakage.

Standardize tooling. Use of catalog-standard tooling has the advantage of lowering costs and improving acquisition lead times. Standards should be used as often as possible in place of blue print specials.

Control tooling usage. Tool consumption should be monitored continuously in order to flag sudden increases in use, perhaps because of material problems, etcetera. When sudden fluctuations occur, the appropriate support groups should be notified. For example, process engineering can address breakage problems and stores can pro-actively address potential inventory problems.

Sound tool management not only affects costs and efficiencies but improves the quality of machined parts. When tools are run beyond their recommended life and become dull, the capability of the machine tool diminishes. For example, a machine running under near optimal conditions with a fresh tool may be specified for a CP_k of 1.33 (66 parts out of specification per million), but as a tool wears and becomes dull, the cutting forces change and the rate of tool wear increases, causing a decrease in the capability of the machine. In some cutting operations, such as turning, the machine tools are manually compensated for tool wear. The more the tool wears, the more frequently the machine tool needs to be compensated, and the greater the probability of running parts out of specification. Figure 2 compares cutting characteristics of both sharp and dull tooling to illustrate the affect of dull tooling on operation control. As cutters wear on operations such as turning, control characteristics vary and become harder to maintain, and thus require more operator adjustment.

As tooling dulls, the rate of tool wear, and therefore, the rate of tool compensation increases. The hypothetical example of Figure 2 compares the performance of a dull and sharp tool in an OD turning operation. With sharp tooling, tool wear is gradual and compensation is easily predicted. However, as tooling becomes dull, the rate of tool wear increases. As the example illustrates, the sample gage frequency becomes invalid allowing parts to fall out of specification. Also, accurate compensation becomes more difficult. Additionally, as the tool wears the standard deviation of the measured dimension increases.

3.2 Other Organizational Requirements

Tool management cannot be as effective in an organization that is not focused on SPC techniques, scrap management, and accounting performance. To fully understand tool

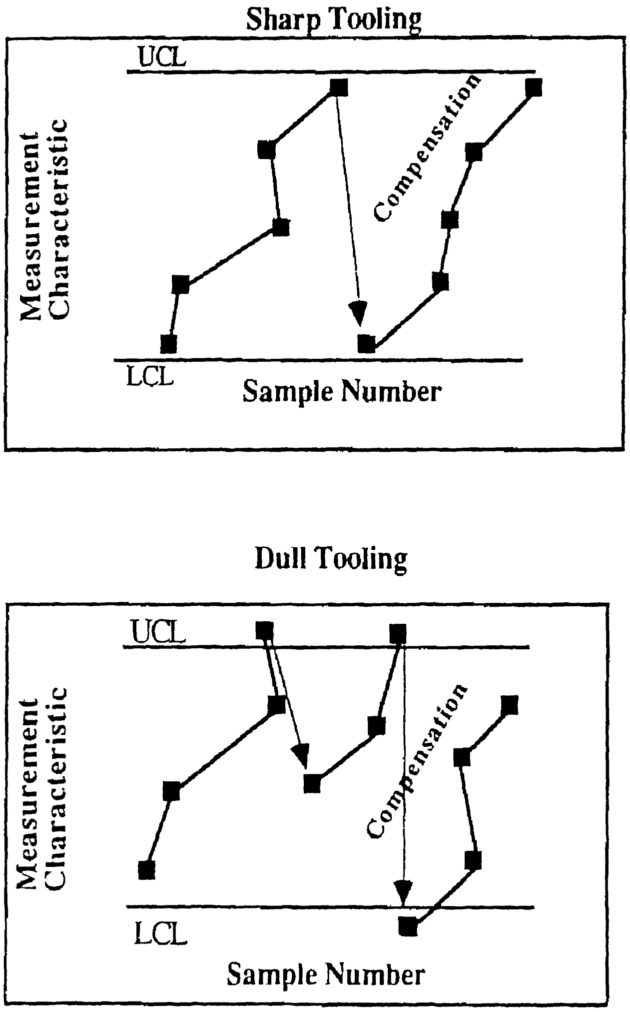


Figure 2. Comparison Between Cutting Characteristics of Sharp and Dull Tooling.

performance, SPC charting of part control characteristics is required. Charting shows how part characteristics perform over time. Machine capability and tool performance are shown in the data. It is possible to misdiagnose a capability problem as a tooling problem when proper SPC charting is not used. The following example demonstrates this:

> *In a department responsible for the manufacture of internal gears, Fellows shaper machines were continuously down for tool changes and machine adjustments because parts were measured out of specification limits. After implementing control charts, it immediately became apparent that the operation was not capable of producing parts 100% to blueprint. This indicated that when the part had measured out of specification, it was just a random occurrence of the statistical distribution of the control characteristic. If the next part had been measured (without a tool change occurring), then the probability of it being in specification would be just as likely as if the tool had been changed. Now that charting is in place, tools are only changed when the control characteristic parameters begin to move away from a nominal value and exceed the control limits. Now that the process is*

understood, the root of the problem can be properly addressed: lack of machine and tooling capability. Tooling is no longer wrongly blamed. Since the charts have been implemented (and the machine capability fixed), the department has gone from seven to five days of operation per week.

Accounting systems should adequately track the performance of tool management. Data should be detailed enough to identify which opportunities can make the largest impacts. Finally, since poor tool management results in scrap, all non-conforming parts should be tracked and identified by operation. It is ideal if all scrap parts remain near the operation at which they were produced so that management could visually identify stations producing high volumes of scrap, and then know what problems to be solving.

4. OUTLINING A NEW TOOL MANAGEMENT SYSTEM FOR GMPT

The objective of this section is to present a comprehensive tool management system that can be implemented at the shop floor level of manufacturing. This system is designed to work within the confines and constraints of the existing Powertrain organizational framework, yet address all concerns mentioned in Section 3.1. This approach is consistent with past approaches to upgrade tool management capabilities. For example, Martin [15] reports on the efforts of the Van Dorn Plastics Machinery Co. to incorporate tool management functions for the purposes of decreasing tool change times and tooling inventory. They too then identified future tooling needs. To achieve all of the objectives, we have identified ten areas to focus on. In the following discussion of these, we explain the desired impact, and then describe how to incorporate them into a full scale tool management program.

4.1 Tool Change

Tool change policies are a fundamental issue of tool management. Without appropriate tool change policies, other elements of tool management are less effective. Our first task in developing tool change policies was to designate desired tool change frequencies or tool life estimates. Tool change counts can be based on a combination of process engineering (considering speeds and feeds), tool suppliers, and operator input. Once these counts are established, the next task is to determine what type of tool change system is appropriate. Based on our criteria that all manufacturing equipment should have a tool change policy and that the method be auditable and controllable, the four following methods for scheduling a tool change were determined to be acceptable for the 4T80E product line:

- **Tool Change Software Programs.** These include Fanuc's Tool Management program and specially written software macro's. We recommend using this type of tool change management on lathes running six or more tools and machining centers with four or more tools.
- **Production Quality Control Charts.** In some processes, it is appropriate to use standard SPC average and range charts to help to determine the appropriate time to change tools.
- **Logboards.** Logboards (see Table 3) are simply a means to track tool change (especially between shifts). Logboards are to be used when operations are simple enough to manually monitor and where more sophisticated methods are not required or useful.
- **Automatic Monitoring.** Grinders and other production equipment can easily use limit switches to indicate when a desired tool change should occur, for example, when the estimated tool life has expired.

Table 3. Tool Change Logboard.

STATION NUMBER	LAST CHANGE	TOOL CHANGE FREQUENCY	NEXT CHANGE

4.2 Limit Downtime During Tool Change

An objective of tool management is to make tool change as efficient as possible. This can be accomplished by three means: having spare and preset tools at each operation, scheduling tool change for off shifts or breaks (when possible), and designing machines and tools for quick tool changes. Often an operator has to chase tools down while leaving a machine idle. This can be eliminated by having the required tools available at the machine. For all machines using tools that require a manual preset, we recommend using tool boards. Maintaining minimal levels of required tooling at each machine allows potential shortages to be detected before they become critical. In applications where multiple tool changes are to occur, such as drill heads in transfer machinery (with up to 25 tools per head in some applications), tool carts can be used so that entire set-ups can be moved easily to the station where the multiple changes will occur. The following example illustrates the need to have preset tools available:

> *In one case, a machine had been down for several shifts because it was having trouble maintaining a critical characteristic. Because the process was about to shut down production, two personnel from the plant managers' staff were on hand as well as a team of engineers. In an attempt to improve the micro finish, an adjustment was made to the boring tool performing the operation. As the job setter made the adjustment, a component on the tool broke. For the next hour, everybody sat idle as production chased components to assemble a new boring tool.*

Locating tool presetters, tooling, and tool boards near the operation is important. Fiat Auto SpA, for example, attributes a change from central to local tool storage as helping to contribute to a 30% increase in productivity in some operations and a 7% reduction in total machining costs for gear boxes. Additionally, in a focused factory layout with fixed schedules, operators can rarely be 100% loaded, so the presetting can usually be fit into their job function.

Machine tools often have the ability to decrease productive downtime by placing duplicate sets of tooling on open turret positions in a tool magazine. With duplication, if a tool breaks or it has run its specified amount of cycles, the machine can automatically change to a duplicate tool without missing a cycle. Automatically changing tools decreases productive downtime by allowing tool change to occur on off shifts, between shifts, or during operator breaks. Also, tools can be changed during machine idle time caused by bottlenecks, assuming a limited buffer between operations.

Finally, tool length and other necessary data should be automatically transferred into a CNC controller after tool qualification, where possible. Unfortunately, this could require extensive DNC or equipment investment, which is currently infeasible.

4.3 Utilize Refurbished Tools

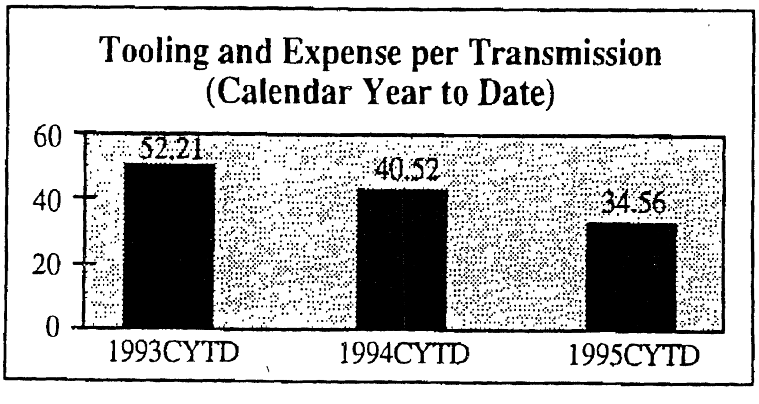
One method to help reduce tool costs is to resharpen a tool when needed and to increase the number of times each tool is re-sharpened. However, when new tooling is available to all production personnel, there has been a tendency to pull new tooling rather than check cutter grind for availability. In addition, if an operator is required to chase tools, it is at the expense of productivity. A solution is to assign a tool chaser to provide all tooling to manufacturing. The tool chaser's priority should be to utilize reground tooling. The tool chaser should be able to see potential shortages and communicate these to Cutter Grind concerning when tools will be required.

The tool chaser can also work with cutter grind on resolving on-going quality issues. With single point tool control, hoarding can be reduced, by only providing new tooling in exchange for dull. A kind of a kanban system can be used: new tooling is only exchanged for old tooling. For example, Figure 3 shows the tooling and expense costs (dollars) per transmission on the 4T80E product line. (This does not include tooling and expenses for the transmission case). Much of the reductions in tooling costs shown in Figure 3 can be attributed to the assignment of a tool chaser to production that occurred in June 1994. His additional coordinating duties (as recommended here) should reduce costs further.

So to replenish worn tools, priority should be given to regrinding dull tools and replacing inserts where possible. Only when refurbishing is no longer possible should new tools be purchased.

4.4 Broken Tool Detection / Wear Monitoring

Some machining center applications use up to 20 tools to perform an operation. In these operations, if a part is mis-clamped or was mis-machined from a previous operation, some or all of the tooling can be damaged (in some applications, this tooling may exceed $30,000). In applications where these conditions exist, it may be appropriate to use a broken tool detector or tool



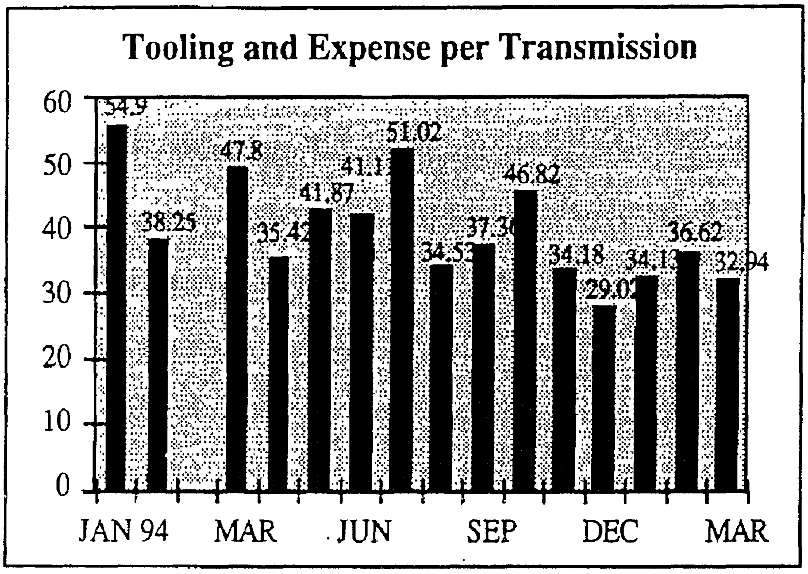


Figure 3. Tool and Expense Cost per Transmission for the 4T80E Product Line.

wear monitoring device. These units measure characteristics including motor horsepower, acoustics, or power load factors, then compare readings to a specified set of parameters. If the results are not as specified, it may be an indication that a tool is excessively worn or broken. The tool monitoring device will then shut down the machine before any further damage can occur. Because these devices generally cost under $2,000.00, only one success need occur per machine for the device to pay for itself So far, success of these devices has been limited in our facility, but this may be attributed to a lack of training of production and maintenance personnel and a lack of consistent use. We suggest implementing tool monitoring devices on a trial basis before full scale implementation.

4.5 Track Out-of-Specification Tooling

Non-conforming tooling results in unnecessary costs and downtime. With tool inventories kept at a minimum, often the repair expense must be incurred in-house in order to keep production rolling. This not only disrupts manufacturing, but creates inefficiencies by requiring support groups to alter the tool. To resolve these problems, non-conforming tooling should be tracked and reported. With tracking, engineering efforts can be directed at solving tooling problems. These problems can include blueprint discrepancies, non-robust designs, and cutter grind discrepancies. Also, the data can be used to remove problematic vendors from purchasing bid lists.

4.6 Monitor Tool Use

With tool change frequencies and production schedules known, the optimal amount of tool consumption can be determined. By recording the number of copies of each tool delivered, the tool chaser can compare the use and check to see if it falls within control parameters (for example +/- 10% of optimal). If the number falls outside of the parameters, investigation should be initiated. These measures can also be used to flag cases where tool management elements are not being conformed to. Reporting problem tooling will allow production personnel to most efficiently address tooling issues. The following is an example of what may occur when sudden fluctuations in tool use go unchecked:

> *One department was experiencing a micro structure problem (hard spots) which resulted in unpredictable tool failure. The department was using tools at a rate two times the normal rate. Because they did not notify stores about the problem, proactive measures could not be taken, and a stock-out occurred.*

4.7 Identify Engineering Opportunities

With tooling costs understood, attention can be focused on extending cutter life and reducing downtime for tool change. Engineering efforts should focus on tool use optimization, in the cases which have the potential to make the biggest impact on tooling budgets. This includes determining better estimates of tool life and determining the best speeds, feeds, and cutter designs.

Another opportunity for large cost savings is in tool standardization. Tools should be specified for multiple purposes. For example, common tools should be used for different operations. We recommend that tooling be standardized as much as possible. Unique tools can be classified as special tooling. Tool standardization sometimes requires redesigning the part or the process (Grey et al. [8]). Standardization reduces tool inventory requirements.

Standardization also reduces data management and can help improve reliability by reducing the need for custom special tools, which could require long lead times for delivery (Hartley [12]). Group technology methodologies have been proposed to aid in process planning efforts (see

Burbidge [2, 3] and Chang and Wysk [4]). Most of these are limited to the generation of tool commonality subsets.

4.8 Special Considerations for Flexible Equipment Requiring Model Changeover

Earlier in the paper, we note that the only department having model changeovers was that producing sun gears and pinions. Because of these changeovers, tooling often was changed prior to the end of its life. Often these tool usages were not tagged or recorded and therefore when they were reinstalled, expected remaining tool life was not known. This problem can be addressed by designating areas for in-process cutting tools. As an audit procedure, these tools are periodically checked for conformance to proper tagging procedure (i.e., cycles remaining).

Another issue in this department pertained to installing new shave cutters. Because shave cutters have varying diameters, depending on how many times they were reground (as the cutter is resharpened, the diameter gets smaller), the shave machines require varying set-up parameters. Because these cutters are shipped to manufacturing without known diameters, operators have to adjust by trial and error to get a part within specification limits. In some cases, a large diameter cutter replaces a smaller cutter causing the machine to wreck and damage to occur to the $3,000.00 cutter. A recommendation for improving such problems is to have the cutter measured prior to shipping so that the operator simply needs to input the provided offset into the CNC controller.

4.9 Audits

In order to assure compliance to the proposed elements of tool management, we suggest incorporating a tool audit into the existing departmental quality and procedure audit. Quality and procedure audits are used as a means to assure that documented processes are in place and are being conformed to. Auditing is a critical element of our proposed tool management program because of the frequency of personnel change and the likelihood that all elements will not be maintained without monitoring. The following are some elements that should be incorporated into the proposed procedure audit:

- All dull tools should be tagged and placed in designated dull tool pick-up areas;
- Tool boards should be checked for minimum quantities of required preset tooling;

- All in-process tooling should have tags showing how many cycles have been run and how many cycles are left;
- All tool monitoring equipment should be checked for functionality;
- Tool change should be audited for compliance to the designated procedures;
- Tools should not be hoarded.

4.10 Tool Inventory

The number of tools available of each type and the cutting life of each tool should be automatically tracked. Once the appropriate purchasers are identified, we recommend using tool usage rates and inventory information to automatically place tooling replacement purchase orders. Ranky [18] describes some data structures for these purposes to use in a tool management system architecture.

5. LESSONS LEARNED FOR IMPLEMENTING AND MAINTAINING TOOL MANAGEMENT

Most of the tool management techniques discussed are neither very difficult nor expensive to implement, but the real drivers to a successful tool management system are management commitment to problem solving, total quality improvement, and worker empowerment. The most important lessons learned are not of any technological breakthroughs, or innovative tool management techniques, but of the importance of using appropriate performance metrics and management's drive towards continuous improvement for the successful implementation and sustainment of a tool management program.

This section outlines an implementation plan for tool management and also discusses organizational strategies for sustaining the gains and assuring long term success.

5.1 Implementation Strategy

The following implementation strategy is suitable to develop and maintain an integrated tool management system:

1. Assign cross-functional teams to collect tool life data and document tool management procedures.
2. Assign an expert to develop and investigate technological options.

3. Reach consensus on the best tool management practices. This should include input from plant staff and managers.

4. Catalog tools and the appropriate change frequency.

5. Document the tool change methods.

6. Rank the possible tooling projects to be worked on according to the current cost of poor quality. Focus on the 10 elements discussed in Section 4.

7. Set-up appropriate metrics to measure performance and improvements.

8. Drive and use the metrics.

9. Train Kaizen teams to help implement tool management details and to develop improvement goals.

10. Set-up process audit procedures to measure and monitor progress.

5.2 Know Your Costs

When operating with limited resources, it is important that these resources are directed at the projects which can make the most impact to the bottom line. If there is not a sufficient data collection system in place, personnel is likely to be working on some projects that are not the highest priority. Additionally, hidden costs may not be known. Cost of poor quality (COPQ) measurements should be used to drive the project selection criteria. COPQ categories for tool management should include rework, out-of-spec parts, scrap, tooling costs, and downtime associated with the tool change process. Currently there is no formal cost tracking system for tooling at Willow Run.

5.3 Utilize Cross Functional Teams

The core of these teams should be composed of operators and process and tool specialists, and can include quality experts, industrial engineers (particularly for input to lean manufacturing), crib and stores personnel, business managers, cutter grind specialist, tool vendors, and others. In the past, teams that we have participated in that did not have the proper cross functionality would often chase wrong, nonproductive leads that could have been avoided had the right personnel been present.

5.4 Use of Problem Solving Techniques

In the example of the Fellows gear shaper (see Section 3.2), production had wrongly identified "variation of tool life" as the driver of their up-time and productivity problems. Eventually, after several months of difficulties, control charts were utilized and machine capability was identified as the primary cause, and not tool variation. In this example, the process was not initially correctly characterized and unnecessary time, cost, and effort were invested into tooling. Many data-driven problem-solving techniques are available to help identify the correct problems to work on.

5.5 Kaizen Practices

Kaizen focuses on continuous incremental process improvements. Success of Kaisan is highly dependent on management's commitment to training and operator empowerment. At Powertrain, a fixed schedule, with semi-dedicated equipment, created limitations in operator balancing. Relaxing a fixed schedule would allow operators time to use Kaisan principles to improve their process. Again, having appropriate performance metrics is important.

5.6 Use of Specialists

Many of the CNC machine tools used at GM were technologically sophisticated and most process engineers were not adequately aware of all of the options available to them. In the specification of new tooling and the implementation of tool management, a local expect should be trained to check that the available technology is well utilized. As a result of not having such expertise, at Willow Run many of the automatic tool change and broken tool detection features of the CNC machine tools were not being used, even though these were paid-for features of these CNC machine tools.

5.7 Do it Right the First Time

Tool management issues should be considered very early on, and as soon as possible during the process design and manufacturing layout of new programs. Once in production, changes to process are both time consuming and costly.

All of these steps are necesary to get the benefits from an initial tool management system.

6. IMPROVING TOOL MANAGEMENT BEYOND THE FACTORY FLOOR

The proposed tool management procedures suggested in Section 4 are only part of what is needed, because we could only focus on aspects of tool management that manufacturing could control. These suggestions should be a vast improvement, but are just a starting point. In this section, we remove the previously presented organizational and managerial constraints and examine the tool management needs in the GM Willow Run facility from a clean sheet of paper. This overall approach has been taken by the Van Dorn Plastics Machinery Co. also. After proposing initial simple tool management procedures, they determined a future wish list of additional features and improvements (see Martin [15]).

6.1 Automatic Reporting Systems

One of the shortcomings of the prescribed tooling system of Section 4 is the means for tracking and controlling tool use. In this system, we rely on a tool chaser to control tooling for the entire product line. The tool chaser is supposed to compare actual use to an optimal desired usage level and report any discrepancies. There are some shortcomings of this method. It is cumbersome, requiring the tool chaser to manually track tool use, compare it to the desired parameters, and generate a report. Also, it is possible for tools to be pulled without the tool chaser being notified. A more desirable method is to automatically track tool use through the disbursement system of the cribs. We recommend that the future tooling system be specified as follows:

- The system should track tool use by department and machine numbers;
- Tool use should automatically be compared to an optimal level, calculated based on specified cycles per tool. The system should have control limits and flag discrepancies to avert potential stock-outs;
- The system should track tooling in cutter grind and generate regrind schedules. A kanban-like system could be used. For tracking purposes, all dull tools should be channeled through the crib, or remotely entered into the disbursement system from cutter grind;
- The system should automatically generate reports of performance to schedule for both cutter grind and outside tooling suppliers;
- The system should automatically track and report any nonconforming materials. This information should be passed on to a different database for Purchasing purposes;
- The system should be designed so that it could provide information to another database that allows suppliers to conduct business on-line.

These latter two suggestions relate to different databases. First, there could be problems with an outside system that is not connected to the process. Also, it may not be desirable for one system to do it all.

We do not recommend canned systems, such as the Tool Management software of Kennametal Inc., for this particular GM application because of the sophistication of the Willow Run indirect materials system. The Willow Run system is tied to other plant sites as well as Purchasing. Integration of a canned system would be difficult. Therefore, modification or overhaul of the existing system to incorporate all specified desired attributes is recommended. Also, running a canned system in parallel would not be efficient.

6.2 Organizational Restructuring

There are two future organizational changes that can help improve tool management plant-wide. The first recommendation is to combine Cutter Grind, General Stores/Cribs, and the production tool chaser into one indirect materials service organization. The second is to create a position of manufacturing tool manager.

Currently, Cutter Grind, Stores/Cribs, and the tool chasers report to separate functional heads. As a result, there is little cooperative effort and a great deal of finger pointing. Combining the groups would give them sole ownership of cutting tool support. The following can be some benefits of combining the groups:

- One entity would be responsible for the servicing of cutting tools rather than several;
- Financial measures could more readily be designed to grade performance of the group;
- Reporting to the same functional head would encourage problem resolution rather than finger pointing;
- The organization would be encouraged to make use of reground tools rather than purchasing new;
- The group would have control over the <u>entire</u> Willow Run tool inventories;
- Better decisions could be made regarding outsourcing issues;
- Redundancies of functions would be eliminated.

The other suggestion is to create a champion of tool management who reports directly to manufacturing. The responsibilities of this position would include the following:

- Develop uniform tool management practices for the entire plant;
- Provide manufacturing support to tool management systems;
- Help monitor the tool management practices; conduct or supervise audits of tool management systems;
- Advise engineers working on new projects so that tool management policies are considered.

With daily tooling expenditures exceeding $60,000.00 per day, the position could easily be cost justified. One recommendation is that the position report to a manufacturing manager of sufficient level to foster the urgency and cooperation required in implementing tool management programs.

6.3 Purchasing Practices

Innovative new purchasing practices could produce additional benefits of better tool management procedures. The following three suggestions aim to improve tool management through enhancements to the purchasing system:

1. A value purchasing criteria should be used in supplier selection;
2. Innovative supplier alliances should be formed and evergreen contracts developed;
3. Just-in-time indirect materials purchasing should begin.

As previously mentioned, the perception is that cutting tools are purchased on a price consideration only policy, rather than quality, lead-time, and service. In GM's Saturn Division, suppliers are selected based on input from employees in Manufacturing Engineering, Finance, Purchasing, Material Management, and the UAW. As a team, they evaluate potential suppliers based on quality, reliability, service, responsiveness, people focus, financial strength, cost competitiveness, and the firm's overall health and welfare. Then they also evaluate how well the supplier fits into the Saturn organization. Only after they meet all of these criteria could they be selected.

Next, steps should be taken to form innovative alliances. Limiting the amount of suppliers makes mutually beneficial partnerships possible. According to Green [9], "these business alliances have been known to result in cost savings of 10% to 25% for the manufacturer." At Saturn, they have negotiated an evergreen contract with Kennametal Inc. for all of their cutting tool needs.

Instead of spending time and resources quoting tools, they focus on process improvements and resolving cutting problems. Because of the desire to maintain their long term contract, Kennametal Inc. would rather provide Saturn a tool manufactured by another supplier, than provide a Kennametal tool that was not sufficient for the application.

Additional benefits of the partnerships is the ability to reduce inventory. Decreasing the leadtimes on cutting tool procurement can minimize the probability of stockouts and reduce inventory holding costs. Table 4 and Figure 4 show the annual inventory costs as a function of the purchase lead time for a hypothetical tool costing $500.00 and with an average use of 10 per week. Receiving evergreen contracts can allow suppliers to produce tools efficiently without the concern of obsolescence.

6.4 Future Product and Process Design

Best practices of tool management should be incorporated into the design of new products and processes. Some suggestions for creating products and processes that are friendly to tool management are as follows:

- Create a cutting tool library on CAD so that product designers and process engineers could consider existing tooling when making design and processing decisions;
- Design products and processes that use standard tooling;

Table 4. Affect of Purchase Leadtime on Inventory Holding Costs.

LEADTIME (WEEKS)	USE/ WEEK	TOOL COST	RE-ORDER QUANTITY	AVERAGE INVENTORY	COST OF CAPITAL	INVENTORY HOLDING COST $
0	10	500	0	0	0.2	0
1	10	500	10	5	0.2	500
2	10	500	20	10	0.2	1000
3	10	500	30	15	0.2	1500
4	10	500	40	20	0.2	2000
5	10	500	50	25	0.2	2500
6	10	500	60	30	0.2	3000
7	10	500	70	35	0.2	3500
8	10	500	80	40	0.2	4000
9	10	500	90	45	0.2	4500
10	10	500	100	50	0.2	5000
11	10	500	110	55	0.2	5500
12	10	500	120	60	0.2	6000
13	10	500	130	65	0.2	6500
14	10	500	140	70	0.2	7000
15	10	500	150	75	0.2	7500

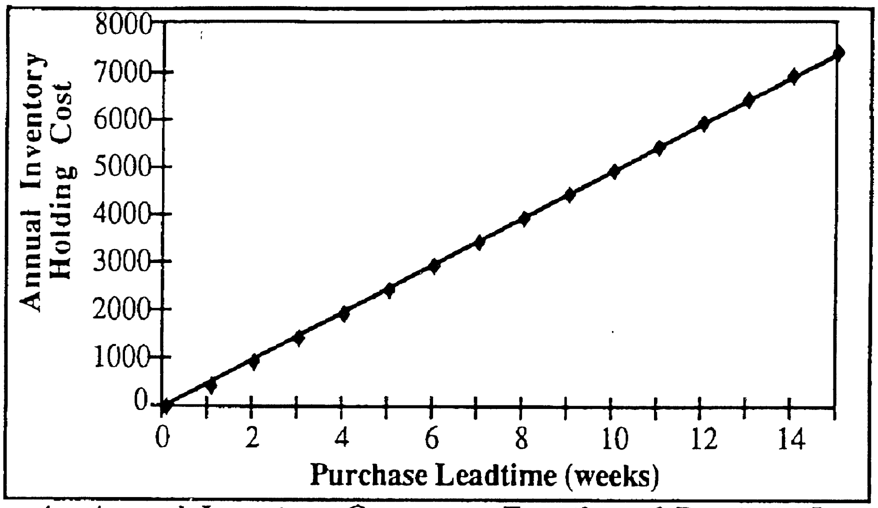


Figure 4. Annual Inventory Costs as a Function of Purchase Leadtime

- In procuring tooling and production equipment, use standard cutting tools and tool holder styles to eliminate multiple set-ups of similar tooling. For example, within a plant there may be several operations machining a hole to the same specifications, but because each piece of equipment has different style spindles or tool holders, they may require different cutting tools;
- Set-up the production processes to readily utilize the existing and future tool management system.
- Adaptive control could be used in some applications. This involves automatically increasing or decreasing the feed rate, based on a comparison of the preset horsepower value with the actual reading obtained during the cut.

6.5 Tool Management Data Base

Many of these future recommendations require a common tool management data base. The data record for each tool type can then be linked to suppliers, parts, machines, operations, tool crib, ... It is then easier to track tool use, life, repair, ... (Gruver and Senninger [10]). Such a common data base is necessary to capture the interaction between the various components of a tool management system.

Data on the behavior of tools under different machining conditions is required for process planning and tool selection and in coding and classifying tools for the purpose of standardization. Each tool must be continuously monitored for wear to plan for replacement, regrinding, or purchase.

Effective tool management can be evaluated by how tooling decisions and information are used to integrate the real-time control of both tools and parts with production planning and tooling inventory control. Several companies have developed sophisticated information systems to: coordinate delivery of the proper tools to specific machines in time; provide location information; correlate the number of tools needed for the quantity of parts to be produced; and offer acceptable substitute tools when needed (Gaymon [6] and Wick [21]). These tool delivery systems can interface with machine loading and sequencing functions. Bar-code labeling of tools or tool cabinets or memory chips embedded in the shanks of toolholders can be used to track tools and collect real-time data (Cumings [5] and Ryan [19]). In lieu of these developments, it is possible to bypass many of the static-deterministic models of tool life and move directly to adaptive control schemes, where tool performance is directly controlled during a machining operation (Gray et al. [8]).

Berr and Falkenburg [1] provide statistics indicating that in practice, for each tool type, there are at least three duplicate tools required: one in a tool magazine, one as a backup (centralized or on a relevant machine), and one in preparation (i.e., being refurbished, inspected, reconditioned, preset, or mounted into the tool shank). Moreover, the number of tool types in storage increases over time, because of factors such as new product introductions, engineering changes in existing products, and the availability of more advanced tooling materials. The appropriate number of tools to be purchased of each tool type must also be determined (Graver and McGinnis [7]).

Optimal tool reorder points and safety stock levels are not yet addressed in the literature. Custom tools can shorten processing times, but are more expensive and require extensive purchase lead times. This tradeoff has not yet been studied; nor has the tradeoff between tool availability, manufacturing capacity, tool reorder points, and the overall investment in tool stocks (Gray et al. [8]).

7. SUMMARY AND CONCLUSIONS

Tool management impacts the bottom line through machine utilization, overtime, scrap, indirect materials, rework, and total tool costs. Tooling has been estimated to account for 25-30% of the cost of production (Cumings [5]). At GMPT, incidences resulting from lack of tool management practices were seen to be significant and costly. Significant issues were lack of focus on tool management and costs associated with tool management, lack of coordination of tool management efforts, poor systems, and lack of ownership for all tool management elements.

After identifying typical problems occurring at GMPT and describing the fundamentals of tool management, we discuss the implementation of a tool management system. Our approach focuses on three main elements: controls and procedures at the production floor level that can be achieved with relative ease, organization issues, and system integration.

Section 4 identifies areas where focus is required:

1. Tool Change
2. Limit Downtime During Tool Change
3. Utilize Refurbished Tools
4. Broken Tool Detection/Tool Wear Monitoring
5. Track Out-of-Specification Tooling
6. Monitor Tool Use
7. Identify Engineering Opportunities
8. Control of Tooling in Flexible Equipment
9. Auditing
10. Tracking Tool Inventory

Any comprehensive tool management system should address these items.

Some of the more important conclusions were that for a tool management system to be fully effective, an organization should be committed to total quality principals. Critical areas are identified in Section 5.

Finally, we make recommendations on fully integrating the organization into the tool management system. Recommendations included: automating the reporting systems to track toolings and evaluate performance; restructuring the organization to give clear ownership to tool management elements; incorporating innovative purchasing practices; considering tooling in the design process; and building a tool management data base.

An integrated system-wide tool management system is a company's ultimate goal. This paper outlines an evolutionary approach to this goal, by following the steps of continuous improvement. Some basic tool management functions often need to be developed and put into place first, to help set the stage and mindset necessary for an eventual first-class tool management system.

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APPENDIX

Table 1. Manufacturing Equipment Used on the 4T80E Product Line.

Part Type	Operation	Type	Manufacturer / Model	Quantity
Valve Bodies	drill, mill	dial	Standard	1
	drill, mill	dial	Kingsbury	1
	boring	machine center	Toyoda FA550	10
Accumulator	drill, mill, bore	dial	Kingsbury	1
Pumps	grind	vertical grind	Mattisson	4
	grind	double disk	Gardner SDG5	3
	drill, ream, bore	machine center	Mazak h400n	5
	drill, ream, bore	machine center	Toyoda FA550	8
	drill, mill	dial	Kingsbury	1
	grinder	vertical grind	Blanchard	1
Flange	turning	horizontal lathe	Hardinge Conquest 51	5
	lathe	horizontal	Suga ST200	3
	drill	special	Schrader	2
	spline	shaper	Fellows 10-2	2
	spline	shaper	Pfauter PE150	1
	lathe	vertical	Olofsson SV5	2
	grinder	angle head	Norton	2
	polish	polisher	Masco Super Finisher	1
Final Drive Sun Gear Shaft	lathe	horizontal	Hardinge Conquest T42	8
	drill	machine center	Accroloc M. C.	2
	grind	plunge	Cincinatti Millicron	1
	polish	polisher	Masco Super Finisher	1
Input Shaft	turn	vertical lathe	Hardinge VTL100	5
	turn	vertical lathe	Olofsson 1270SS	3
	turn	horizontal lathe	Hardinge 51	2
	drill	machining center	Accroloc M. C.	3
	spline	hob	Mitsubishi GB15CNC	1
	spline	hob	Pfauter PE150	1
	turn	vertical lathe	Olofsson SV5	2
Hub & 3rd	lathe	horizontal	Hardinge Conquest 51	6
	spline	spline roller	Grob	2
	punch	piecer	Koppy	6
	drill	special	Schrader	1
	spline	hob	Cleveland Ridgehobber	2
Housings	lathe	horizontal	Hardinge Conguest 51	10
	drill	special	Roberts Tool	1
	mill	Machine Center	Accroloc M. C.	1
	lathe	vertical lathe	Olofsson SV5	3
	grind	plunge	Warner Swaysey	2

Table 1. Continued

Part Type	Operation	Type	Manufacturer / Model	Quantity
Supports (sprocket)	lathe	horizontal	Hardinge Conquest 51	8
	grind	angel head	Norton	2
	spline	shaper	Fellows 10-2	2
	drill	special	Ann Arbor	1
	lathe	vertical	Kingsbury VCT3	1
	lathe	vertical	Hardinge VTL100	4
	drill, bore	dial	Kingsbury	1
	lathe	horizontal	Suga ST200	1
Housing - forward coast clutch	turn	vertical lathe	SMS N50-1	4
	drill	special	Kingsberry	1
	turn	vertical lathe	SMS AC300-2E/A	3
Support - forward coast clutch	shape	shaper	Fellows	1
	shape	hob	Pfauter PSA150	2
	turn	vertical lathe	SMS N50-1	5
	drill	special	Kingsberry	1
	turn	vertical lathe	SMS AC300-2E/A	1
Carriers (planetary)	lathe	horizontal	Hardinge Conquest 42	4
	lathe	vertical	Olofsson 2015ST	2
	spline	broach	U.S.	2
		hob	Cleveland Ridgehobber	4
	drill, ream	mahcine center	Mazak H400N	6
Internal Gears	lathe	vertical	Olofsson SV5	1
	lathe	vertical	Casper	1
	broach	broach	Red Ring	1
	grind			2
	shape gear	broach	Federal	1
	lathe	horizontal lathe	Suga ST200	1
	lathe	horizontal lathe	Hardinge Conquest 42	1
	shape gear	shaper	Fellows 10-2	
	shape gear	shaper		
Pinions & Sun Gears	hob	hob	Pfauter PE80	6
	hob	hob	Mitsubishi GB15CNC	3
	shave	shaver	Mitsubishi FA30CNC	4
	shave	shaver	Redring	8
	grind	grind	Redin	2
	hone	hone	Nagel	2
	grind	grinder	Gardner SDG5	2
	spline	broach	Federal	1
	hob	hob	Mitsubishi GB10CNC	7