

# The Retrofit Advantage: Important Considerations when Retrofitting, Rebuilding or Remanufacturing machine Tools

Without question, your machine tools are among the most vital – and costly – pieces of equipment on your plant floor. For most companies, machine tools represent significant capital investments and must therefore maintain their viability for many years. Keeping them updated with the latest control technologies via a CNC retrofit is one way companies are doing that successfully today. In this whitepaper, we'll address some of the key considerations you should make before implementing a CNC retrofit project on your machine tool. We'll also help you quantify the value of this important decision.



# What to Consider when Retrofitting, Rebuilding or Remanufacturing Machine Tools

## Introduction

A CNC retrofit is a significant investment, so it is important to consider all of the costs and benefits in order to establish a demonstrable return on investment.

Retrofitting is the process of replacing the CNC, servo and spindle systems on an otherwise mechanically sound machine tool to extend its useful life. Rebuilding and remanufacturing typically include a CNC retrofit. The anticipated benefits include a lower cost investment than purchasing a new machine and an improvement in uptime and availability. But there are often other unanticipated benefits to retrofitting including lower energy costs, higher performance and a new level of manufacturing data accessibility.

Manufacturing requirements have dramatically changed in the last two decades, and many new features are now available to support Lean Manufacturing. Retrofitting is a competitive business, so retrofitters will often quote a very basic control system configuration unless you specify the functionality that is important to your operation.

Selecting the best retrofit partner can sometimes be confusing, and it is important to make sure that the company has experience with the specific type of machine tool that is to be upgraded in your facility. It is also essential to ensure that the scope of work is clearly defined for an apples-to-apples comparison of competing proposals, and to establish a long term, win-win relationship with the selected retrofit company.

Justifying the retrofit investment is similar to any other kind of investment. Considering all the financial costs and benefits allows you to calculate an ROI for a comparison with other investment opportunities. By considering all the financial and non-financial benefits associated with the project, you will be able to decide if the retrofit makes sense for your business.

## What is a CNC retrofit?

A CNC retrofit typically upgrades the CNC, the servo motors and drives, the spindle motor and drives, and a portion of the associated wiring and related electromechanical components. Unlike rebuilding and remanufacturing, a CNC retrofit does not include any major repairs to the machine mechanics. A CNC retrofit should not be confused with a CNC conversion, where a manual machine is converted into a CNC machine.

Assuming the machine tool is generally in good shape mechanically, CNC retrofitting is typically the lowest cost solution to improve the overall performance of an older machine tool. Though some electrical subassembly is often performed at the retrofitter's business location, most of the work can be completed at the machine site, avoiding costly machine rigging and transportation costs, and minimizing the time that the machine is out of commission.

Rebuilding typically includes the repair or replacement of some worn mechanical components such as ballscrews, lubrication pumps, safety interlocks, guards, hoses, belts and electrical wiring. The rebuild is typically performed at the rebuilder's facility, so there may be additional transportation and rigging costs.

Remanufacturing goes a step further to repair or replace mechanical components to the original, "as new", factory specification. It is likely that the machine will be completely disassembled, cleaned, inspected, repaired and painted. All pneumatic, hydraulic and electrical systems will be updated. The machine may also be modified or have mechanical accessories added to re-purpose it for a new application. Practically without exception, remanufacturing will take place at the remanufacturer's site.

Deciding whether to retrofit, rebuild or remanufacture depends on the current condition of the machine and the anticipated benefits from the investment. Reviewing maintenance records and part yield statistics may help understand the state of the machines mechanical systems. A ballbar analysis can also be used to diagnose mechanical problems. Retrofit, rebuild and remanufacturing companies will also be able to evaluate the current condition of the machine and recommend the appropriate solution.



## What are the benefits of a CNC retrofit?

There have been significant advances in machine tool technologies in the last twenty years, but these advances may or may not be relevant to a particular machine's application in your business.

There is tremendous retrofit activity in the heavy construction equipment, power-generation, aerospace and defense industries that often use machine tools costing over \$400,000. The large turning centers commonly used in these industries, are not widely manufactured today. These industries also use other specialty machines, manufacturing large parts from difficult-to-machine materials. These applications are often limited more by cutting tool technology than by axis positioning and contouring performance.

Since these machines are typically mission critical, they are well maintained mechanically, and the mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR) issues tend to be driven by their aging electronics. Therefore, a CNC retrofit can deliver significant benefits.

### Lower cost

A retrofit, rebuild or remanufacture will cost somewhere between 1/3 to 2/3 the cost of purchasing a new machine. It is important to recognize not only the differences in purchase price, but also the additional costs of any new tooling requirements, transportation and rigging, modifications or replacement of special foundations, modification of part programs and processes, and the associated training for the operators and maintenance personnel.

When compared with doing nothing and continuing to accept the current availability and performance of an older machine tool, a CNC retrofit can quickly pay for itself.

At the end of a product's anticipated life span, replacement parts often become more difficult to obtain and, therefore, the law of supply and demand tends to drive up their price significantly. Parts may no longer be available locally, so the transportation costs and the total downtime associated with the failure are increased. Certain components may become obsolete, and the only choices are either to repair the original part, or to custom engineer a substitution, increasing direct and indirect costs. A machine that is mission critical or is a bottleneck process may have huge customer satisfaction and cost impacts if lost from production for any extended amount of time.

A retrofit control will significantly reduce CNC maintenance costs. Not only will the retrofit system be more reliable because it is new, but it will be built with substantially more reliable components. The new system will also be provided with a multi-year warranty for parts and perhaps labor.

### Performance

When considering a CNC retrofit, it is important to realize that a significant portion of the benefits will actually be delivered by upgrading the servo and spindle system to a high-speed, digital interface. It does not matter how fast the CNC can process blocks of part program data, if the servo and spindle systems cannot keep up.

The CNC, servo and spindle systems integrated in an older machine tool typically communicate using an analog interface. The CNC commands the desired velocity of the motor with a  $\pm 10$ -volt signal, while a low-resolution, analog or digital feedback devices tell the CNC where the axes are currently positioned. Simple I/O points are used to enable and disable the drive systems, and to report on any drive or motor failures.

The coarse resolution and the noise susceptibility of the analog drive interface limits the achievable speed and accuracy of the system. Tuning traditional analog drive systems is more of an art than a science, requiring specialized tools and resources for even basic system stability.

The modern CNC and the digital servo and spindle drives are so highly integrated, it is best to consider them as a single system. The subsystems communicate over high-speed fiber optic communication paths to provide the required noise-immune bandwidth for very high-resolution, intelligent feedback devices and inter-process communications. Today's high-performance systems can take advantage of 16-million count, serial encoders; even low-end systems are using at least 128K, serial encoders. A large proportion of the advanced capabilities of the modern CNC system are at least partially implemented in the digital servo and spindle systems processors.

The tight integration of today's CNC and digital drive systems are combined with high-speed Ethernet communications, to allow the use of an advanced Windows-based servo tuning application that makes standard servo tuning practically automatic. For advance tuning, engineers now have powerful frequency analysis, Bode plots and Fourier

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analysis tools to analyze and display the servo system response in real-time. These tools are also used to tune spindle systems, since they are also used as servos for rigid tapping and live-tool applications.

Diagnostic systems have also advanced, allowing everything from motor temperature to position deviation to be displayed on the CNC. Precise error messages are displayed on the CNC for each specific potential problem, and common remedies are also provided.

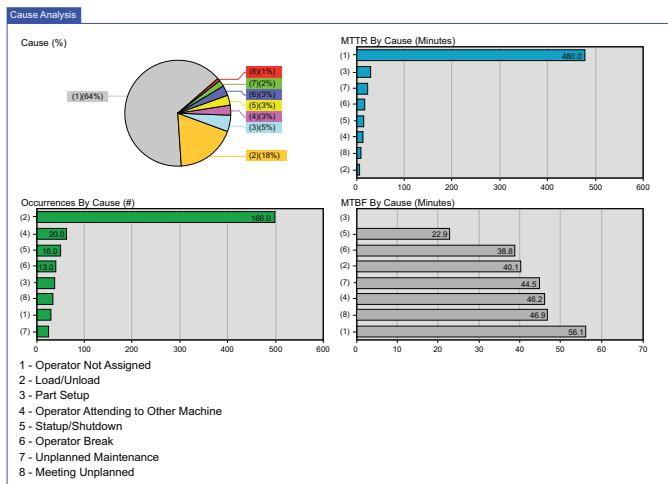
## Energy savings

When decelerating the axes and spindles during normal operation, older systems dumped energy into regeneration resistors, simply burning away expensive electricity.

Current digital drives incorporate advanced electronics that push electrical energy back into the line when decelerating the servo and spindle motors. When combined with the more efficient machining processes provided by the CNC, machine electricity costs can be reduced by as much as 30% to 50%, easily justifying the investment in the new servo and spindle drive technology during a retrofit.

## Improved mean-time-between-failures

Driven by the advances in semi-conductors for consumer electronics, aerospace and military applications, today's CNCs are much more reliable than those that were produced just a few decades ago. The differences are compounded by the fact that the aged electronics integrated into older machines are now into the high-failure rate section at the end of their life cycle curve.



GE Fanuc CNCs now have a mean-time-between-failure (MTBF) value that exceeds 10-years. New CNC features also provide tools to error-proof operator inputs and other process related operations. Error-proofing may prevent the downtime that results from a crash after the misapplication of tooling, materials, part programs or fixtures.

A CNC retrofit will significantly improve the MTBF of a machine tool. This is very important because many retrofit candidates are mission-critical or bottleneck machines.

## Improved mean-time-to-repair

Studies have shown that, though improving MTBF is very important, there is even more of an opportunity to improve uptime by focusing on the time it takes to recover from a failure. Today's operators typically run multiple machines, and assets often sit just waiting for attention.

Advances in CNC communication technology and the associated software now make it possible to alert operators and maintenance personnel to a wide range of process and downtime failures. Notification of symptoms can be sent before a real problem even occurs, allowing predictive and preventative actions to be taken. Features such as tool management, tool life monitoring and tool breakage detection can be combined to apply preventative and automatic recovery strategies.

If the downtime cannot be predicted or prevented, advanced diagnostic tools can be used, locally or remotely, over Ethernet, to reduce mean-time-to-repair (MTTR). Maintenance and Industrial Engineers can view the CNC screens remotely to solve problems over the phone, or at least arrive at the site with the tools and parts to speed recovery.

GE Fanuc CNCs can display a message and an operational history to allow the reconstruction of events that preceded a failure. Diagnostic displays quickly communicate the CNCs general health, and the ladder and IO displays help troubleshoot the CNC-to-machine interface.

Combining the value of alarm monitoring, insightful diagnostic screens, remote access, and basic troubleshooting training for operators, maintenance and process engineers, the mean-time-to-repair of a machine can be dramatically reduced by a retrofit, managing the risk of excess downtime when operators manage multiple machines.

### **Data accessibility and customization**

During the 1990's, the industry was focused largely on the promise of low-cost PC-based CNC technology. A decade later, many of those systems are being replaced by traditional CNC technology because of poor reliability, and the unavailability of legacy personal computer parts. The cost to use industrialized rather than commercial-grade PCs often exceed that of the traditional CNC, and the PC-based systems still have limited parts availability as their components become obsolete. IT departments also fight issues related to viruses and the misuse of company assets when PC-based CNCs are connected on company networks. Installed systems include outdated operating systems that do not support contemporary virus and security protection, and the hardware can not be upgraded to support the newer operating systems.

Manufacturers have since determined that what they really need is robust, high-speed communications and the ability to create custom screens for specialized processes.

For the past decade, all of GE Fanuc CNCs have supported an optional or embedded Ethernet port that provides standard TCP/IP data transfers, and a comprehensive public FOCAS2 API for data collection and control applications. However, since the CNC does not use a public domain operating system such as Microsoft Windows, it is not susceptible to attack by viruses and hackers.

There are several choices available when implementing custom applications. The FOCAS2 API can be used to integrate external PC-based programs. The C-Language Executor option available on GE Fanuc controls provides a powerful, industry standard tool for creating custom displays and implementing control algorithms. The FANUC Picture tool provides an easy-to-use application development environment that has draw-and-click features similar to many common SCADA tools, and it can be integrated with other C-Language Executor applications.

If the Windows development environment is preferred, Microsoft CE provides the Windows interface in an embedded operating system that eliminates virus vulnerability and the unreliable hard disk. GE Fanuc will also be introducing Embedded XP, which supports standard Windows applications, but allows the machine tool retrofitter to select only the operating system components required to support the

application. This reduces system vulnerability and gives the retrofitter the option to choose flash storage over a hard disk, thereby increasing reliability.

### **Improved support**

Technical and training support may be limited on your older CNC. Even if the original manufacturer is still in business, they may not have resources available that are experienced with your particular control vintage.

GE Fanuc protects its sizable installed base of CNC users in the Americas with a comprehensive support offering. Free technical support is available during normal business hours to assist your part programmers, operations staff and maintenance engineers. Support contracts are also available to provide 24/7 technical support. Seasoned application engineers are available to help you decide what features are most beneficial to your operation, and to assist your chosen retrofit partner to implement the wide range of GE Fanuc solutions to maximize their effectiveness. In addition, productivity specialists can review your operations and help identify additional features that may enhance your operational effectiveness, both for the retrofit machine and the other assets in your factories.

### **Standardization**

Many machining operations use a wide range of machine types for a variety of applications including turning, machining, grinding, gear cutting, punching, laser cutting and other specialized applications. There are a few machine tool builders that can offer a comprehensive line of machine tools that cover a significant portion machining applications, but typically the end-user may consider that there is a best-in-class manufacturer available for each type of application.

Control standardization is an important factor to simplify operation, part programming and maintenance, allowing more agility in applying labor resources. The GE Fanuc CNC is available on practically every type of machine tool, providing commonality for the critical machine function. Manufacturers that might offer an alternative CNC as standard will also offer the world's leading control to meet a specific customer's requirements. Therefore, selecting a GE Fanuc CNC for a retrofit is an important element in standardizing manufacturing processes.

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## Features for a lean manufacturing retrofit?

There have been many CNC technology advances in the last twenty years to support the evolution of machining processes. The CNC is now a relative super-computer when compared with the technology that is currently integrated into older machine tools.

With multiple, faster, and distributed microprocessors, and with a magnitude increase in system memory, the CNC can now incorporate advanced software algorithms that can model the machine mechanics, and dynamically compensate for inherent, undesirable mechanical characteristics.

Numerous features have been added to the CNC to reduce setup, minimize downtime, increase processing speeds, minimize minor stoppages, and improve setup and production part yields. Many of these new features address issues that are critical success factors for lean manufacturing environments, and they typically cost less if implemented with a new CNC purchase, including during a retrofit.

### Features for setup reduction

Machine tool setup involves a sequence of time consuming measurements and CNC data-entry steps. Typically, the operator must download the part program, load new tooling into the machine, select fixtures and material, and establish tool geometry, workpiece location and tool wear offsets in the CNC. Aside from being time consuming, both the measurement and the data editing procedures represent opportunities for variation and error to occur.

One traditional setup reduction technique is to move as many steps as possible external or parallel to the machining process. Automatic tool setters and sophisticated jigs and fixtures can have an impact on elapsed production time, especially for medium to high lot size production. However, there are significant investment and operational costs to purchase and manage the additional assets.

If there is an operator assigned to each machine, they may have time to perform some of the external setup, but the current trend is to have operators run multiple machines. There is also a risk that the external setup is invalidated because of an error in the selection or adjustment of the part program, material, fixture, tooling, or an offset value.

External setup provides little advantage for small lot production or lean manufacturing environments, where external setup time can exceed the processing time of the previous job. The cost and lead-time to build or modify jigs and fixtures can also become a competitive disadvantage.

A robust solution is to automate as much of the setup process as possible, and use labor resources to manage multiple machines rather than perform external setup.

### Error-proofing with custom macros

The flexibility required for high-mix manufacturing implies a level of programmability. In fact, most CNCs incorporate some form of parametric programming. GE Fanuc calls this part programming feature Custom Macro B, and it is available on all current and many legacy controls.

Custom Macro B is a BASIC-like language that supports user and system variables, allows branching based on the values of variables, displays messages and interrupts processes. A comprehensive set of mathematical operators and trigonometric functions are supported. Though the original intent of this language was to allow machine tool builders and users to design their own canned cycles, it can be used throughout a part program and in subroutines for a wide range of applications, including error-proofing.

For example, to adjust a tool wear offset, the operator can be prompted to measure a specific part feature and enter the dimension into a spare offset or a macro variable on the CNC display. Custom Macro B can then test the reasonability of the value entered, calculate the variance, and then update the appropriate tool offset automatically, eliminating data-entry and calculation errors, and simplifying the process. Custom Macro B can even eliminate the operator measurement variability by taking the readings directly from an in-process or post-process gage system.

### Custom Macro B Language Features

- Local Variables (parameters/intermediate calculations within a macro)
- Common Variables (shared by all macros)
- Permanent Common Variables (keep values when power is turned off)
- System Variables (read and write CNC data items/generate alarms)
- Standard operations (add, subtract, multiply and divide)
- Trig Functions (Sin, Cosine, Tangent and their inverse)
- Math Functions (SQRT, ABS, ROUND, FIX, FUP, LN, EXP)
- Logical Bitwise Operators (AND, OR, XOR)
- Conversion Functions (BCD to BIN, BIN to BCD)
- Branching (IF-THEN and GOTO)
- Conditional Operators (equals, not equals, less than, less than or equal to, greater than, greater than or equal to)
- Loops (WHILE-DO-END)
- Variety of calling formats with parameters
- Printing of values to a serial port



## Machine tool probing

Today's machine tool probes are fast and robust. They can automatically set tool geometry, tool wear, and workpiece offsets. They can provide values for the 3D Coordinate System Rotation option that can be used for large parts that are difficult to position accurately on the machine table. They can also be used to identify that the correct combination of part program, material blank and fixtures are being used, which is very important when high-value parts are being machined.

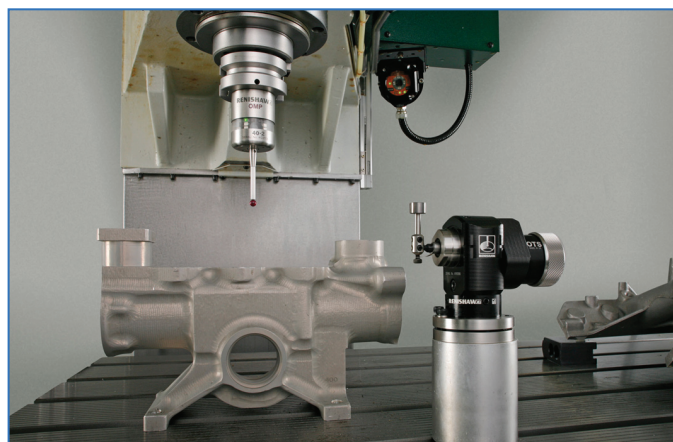
Manufacturers often get concerned about the time required for machine tool probe cycles, but the truth is that they are faster and more accurate than an operator can be. They are consistent, eliminating operator measurement and data-entry time variation for a predictable takt time. They eliminate data entry errors and work through breaks and lunches, increasing throughput and enabling operators to monitor multiple machines without risking deterioration in part quality.

During a CNC retrofit is an ideal time to add a machine tool probe system, or at least make the machine probe-ready. The high-speed skip hardware is standard on current GE Fanuc controls, but the High-Speed Skip software option must be specified. A few simple cables are required to connect the CNC to the probe interface.

## Tool identification systems

If you have invested in an external tool measurement system, it is probable that the machine still sits idle as the operator loads the tools into the machine, careful to put each tool in the correct pocket, and then updates the tool geometry offsets from a printed sheet. Putting a tool in the wrong pocket or a simple typing error can still crash the machine, or at least make bad parts.

Small RFID tags can be mounted in tool holders to transport information back and forth between the tool setter and the CNC. The tool measurement system writes the designated tool pocket and measured tool geometry offset values to the tag. When the tool is installed in the machine, a sensor reads the stored values, checks that the operator placed the tool in the correct pocket, and then automatically sets the tool geometry offsets values in the CNC. The CNC can also write tool usage information back to the RFID tag when a tool is removed, so that appropriate tool maintenance can be performed by the tool crib personnel.



## Operator-friendly tool offsets

Older CNCs had a limited number of offsets that had to be reused for multiple applications including tool length, tool diameter, and tool wear offsets. Part programmers arbitrarily assigned offset numbers to different sections of the part program and it was up to the operator to ensure that the appropriate values were calculated and entered into the correct location in the offset table.

Today's CNCs still support these type of offsets for backwards compatibility purposes, but consider specifying the Tool Offset C option. It separates tool geometry and tool wear offsets to allow more logical data entry, and it provides automatic calculations to combine the two values. Specify a sufficient number of offsets so that each pocket can have its own set of values, eliminating any potential confusion between the part programmer and the operator.

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# What to Consider when Retrofitting, Rebuilding or Remanufacturing Machine Tools

## Expanded part program memory

CNC part program memory space has traditionally been very limited, either by technology or cost. Some manufacturers would prefer to store all the part programs that can be executed on a particular machine tool in the CNC, while others have very large part programs that cannot fit in the space available.

The Data Server combines the features of Ethernet communications and a very large part program storage location. The approved, high-speed flash memory card for the Data Server can handle up to 1G-byte of part programs. Part programs that are larger than the CNC main memory can be paged or streamed from the Data Server. The Data Server includes an FTP (file transfer protocol) server, so it can be accessed in Windows Explorer as just another virtual hard disk folder, providing high-speed, drag-and-drop part program downloads.

## **Features for reducing downtime**

Today's machine tools and CNCs are very reliable, assuming the required preventative maintenance is performed on schedule. Machine crashes related to setup errors, however, remains a source of downtime, so it is important to automate and error-proof as much of the process as possible. However, it is often the inefficiency of the recovery process that contributes the most to machine downtime, not the actual problem and repair.

## Maintenance training

The GE Fanuc CNC is packed full of diagnostic tools to allow you to troubleshoot and recover quickly when a problem occurs. For example, the diagnostics pages provide a single, convenient location to monitor the status of the CNC, servo and spindle systems. The PMC ladder and I/O status pages show the real-time condition of the CNC-to-machine interface. Operational and message history capture the events that preceded a fault. The operator and the maintenance team are often unaware of these and other troubleshooting tools that are integrated into the CNC.

GE Fanuc CNC Maintenance training empowers operators and maintenance engineers to use the available tools to rapidly troubleshoot CNC and machine tool problems. Understanding the basic components of the CNC and machine tool interface, and how they work together, makes locating problems more efficient. Since the machine tool is typically unavailable for several weeks during the retrofit integration, it may be an ideal time to send operators or maintenance engineers for training.



## Remote diagnostics

It is most likely that a new CNC will have an Ethernet port, or that one is available as an option. GE Fanuc's Ethernet port provides a method to remotely diagnose problems using a tool such as the CNC Screen Display Function. Empowering maintenance and industrial engineers to use remote diagnostic tools means they can solve more problems over the phone, or at least turn up on site with appropriate tools and replacement parts.

The CNC Screen Display Function shows all the standard screens, just as if the engineer was standing in front of the machine tool. By setting appropriate passwords on the machine tool interface, the remote user can either be limited to view only, or they can take complete control of the machine tool.

## Backup and restore

One of the most complicated and costly problems to repair on a CNC occurs when critical files are lost, and there is no current backup. Some CNC files are provided by GE Fanuc, but the machine tool builder or retrofitter provides additional files and settings to customize the CNC to a particular machine tool. Other files are created by the end-user to implement process standards or families of parts. Files may be lost or corrupted due to an electrical component failure, a lightning strike, a flood, or some other unexpected event. If these files are not backed-up, it could take a week or more to get the machine back into production.

GE Fanuc's 30-series CNCs incorporate automatic backup of files to flash memory, for one level of data security. The Backup Kit from GE Fanuc provides a low-cost solution to save and restore all the files on current and legacy CNCs. For larger plants or for compliance environments, Proficiency Change Management for CNC can automatically backup, monitor and control critical files. Having a complete backup of the retrofit system will insure against potential excessive downtime to reassemble these critical files.



### Catastrophic crash protection

Machining processes often rely on the fact that a prior process was completed to specification. The classic example is when a tapping tool relies on the fact that a hole has been previously drilled. If the operator forgets to put the correct drill in the correct pocket in the tool changer, or sets the wrong offset or offset value, or the drill simply breaks during machining, a severe crash can occur.

The TSR2 single-sided, laser probe can visually check for missing or broken tools at high-speed, even before coolant has stopped dripping off surfaces. The Unexpected Disturbance Control feature available in current GE Fanuc CNCs monitors the torque generated by the axis drives and trips if it goes above a programmable threshold, protecting the machine from serious damage.

### **Features for increasing processing speed**

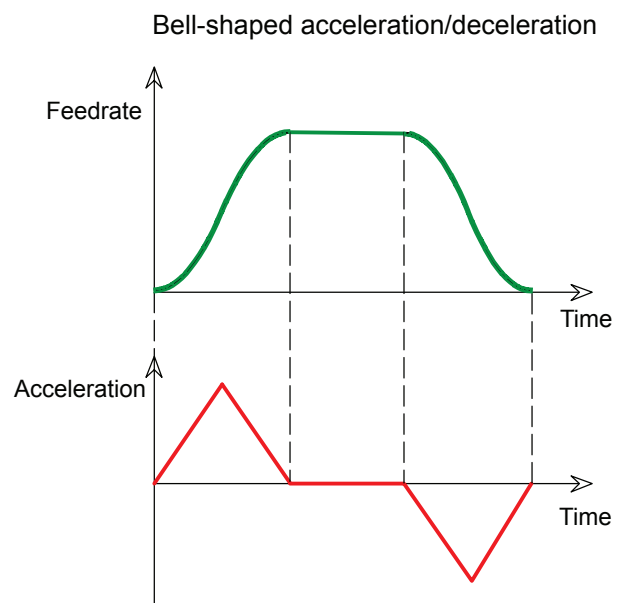
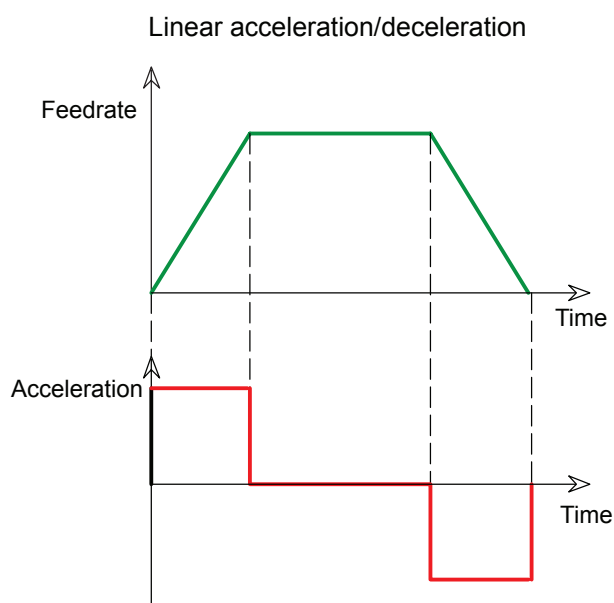
The cycle time for machined parts is typically established by benchmarking. It is often assumed that the benchmark represents the fastest possible processing speed, for specific tool related feed and speed settings. However, machines spend most of the time accelerating and decelerating (acc/dec) between each move, or between each pass of a multi-pass contouring cycle. Feedrates are also often limited below the capacity of the machine and the recommended material cutting parameters to prevent path errors and to accurately reproduce contours.

Accuracy and speed are competing factors in many machining operations. There are several CNC features available to improve the dynamic accuracy of the machine tool and servo system, and the improved accuracy can be traded-off for higher processing speeds.

### Bell-shaped acc/dec

Older machine tool servo systems were based on analog controls, and they featured limited exponential acc/dec or perhaps a simple linear acc/dec. Machine structures often reacted violently to exponential acc/dec because of inherent mechanical resonances. Linear acc/dec is more gentle on mechanical structures, but there is still a time when the axis must go from dead stop to accelerating at the start of a move, and then from decelerating to a dead stop at the end of a move. These transitions are like mini exponential sections in the acc/dec cycle of the machine.

Bell-shaped acc/dec minimizes many of the fundamental problem of machine resonances by using an S-shaped curve. During the first microseconds of a move, the acceleration of an axis is ramped very gently until the linear section is reached. When the axis reaches top speed, or when going from top speed to decelerating, or when decelerating to a stop, the same simple, gentle ramping of acc/dec rate occurs. This typically allows the linear section of the acc/dec curve to be set more aggressive than is possible with standard linear acc/dec, reducing the overall cycle time.



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## High-speed machining functions

High-speed machining is typically associated with cutting aluminum using specialized machines in the aerospace industry. However, the CNC high-speed machining technology can be applied to any machine tool to speed up processing and reduce cycle time by as much as 50%.

Block look ahead, acc/dec before and after interpolation, nano-interpolation, NURBS and automatic feedrate control by corner, circular radius, acceleration, cutting load torque, and jerk are just some of the technologies that can be applied to make the machine more accurate and therefore have the ability to go faster.

Since the axes drive systems have to be tuned on the new retrofit system, it is an ideal time to add some of the high-speed machining options and get the expert tuning needed to maximize the capabilities of the machine.

## Machine tool servo optimization

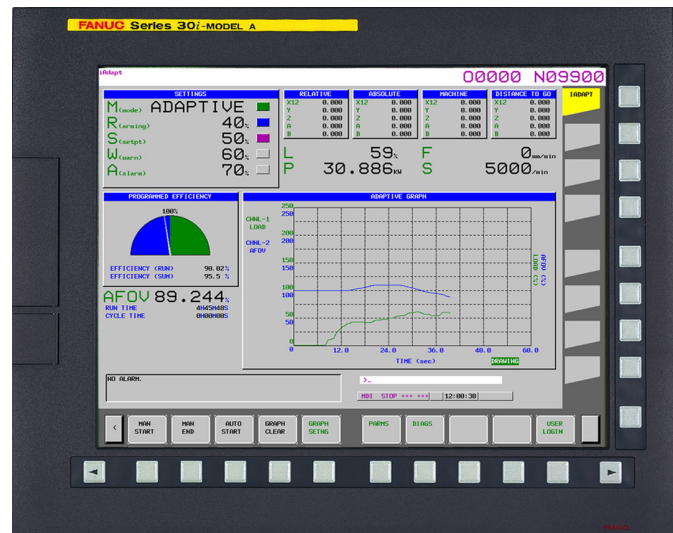
Most machine tools are delivered with only basic servo tuning to ensure stable operation for a wide range of applications. GE Fanuc's experience is that most machines can be improved for specific applications, because the optimum servo tuning for large, heavy parts is significantly different than the optimal servo tuning for smaller, lighter parts.

Machine tool servo optimization combines a consulting service, option activation and specialized servo tuning. An engineer evaluates the integrity of the machine tool and then investigates the various machine tool applications. GE Fanuc can then help specify what performance related options should be included in a retrofit control for that specific machine and application, and can perform the optimization at the end of the machine's commissioning.

## Adaptive control

The only absolute physical limit to the productivity of a machine tool is typically the spindle horsepower available to remove material. Practically, machines are not run at maximum horsepower during finishing cuts because surface finish specifications are more important than productivity. However, even during roughing-cuts, a machine rarely takes a full load because of process variation concerns.

The horsepower required to cut a particular material is proportional to its hardness, the depth and width of cut, and the sharpness of the cutting tool. The hardness of some materials varies from batch to batch, from piece to piece, and even within a cut. The depth-of-cut of the initial passes are often lighter than the subsequent passes because the surface level is unpredictable from part to part. When con-



touring and facing, the width-of-cut may vary continuously. As tools wear, more horsepower is required to cut the same material. All of this potential process variation means that the programmer ordinarily selects a very conservative feedrate, and the machine capabilities are under-utilized.

Adaptive control allows a power level to be specified in the part program along with a target feedrate. This feature automatically adjusts the actual feedrate to maintain a constant horsepower that is suitable for the machine and tooling. As material hardness, depth-of-cut, width-of-cut, and tool condition varies, adaptive control speeds up or slows down the actual feedrate as required, decreasing the overall cycle time by as much as 40%.

## Features for reducing minor stoppages

Traditionally, machine tools required a full time operator to monitor the cutting process. They would stop the machine for a variety of reasons such as measuring parts, updating offsets, replacing worn or broken tooling, and replenishing cutting fluids. When operators are asked to manage more than one piece of equipment, each machine has to become more self-sufficient. Otherwise, there is a risk of lost production whenever two machines need attention at the same time. Eliminating minor stoppages through automation expands capacity by allowing a machine to run unmanned through breaks, lunches and complete shifts.

## Tool life management

Most manufacturers do not have a standardized process for replacing worn tooling or inserts. If a tool is broken, obviously it needs to be replaced, but what about when is a tool worn out? Generally, this is left to the judgment of the operator. A more experienced operator may ignore the

occasional squeal from a cut, whereas a less experienced operator will stop the process and replace the tool or insert immediately. Some operators listen to the cutting process, while others look at the surface finish. Some operators may change tooling after just a few offset adjustments, whereas others get the maximum life from the tool or insert. Waiting too long can result in bad parts, but reacting prematurely increases tooling costs and wastes production capacity.

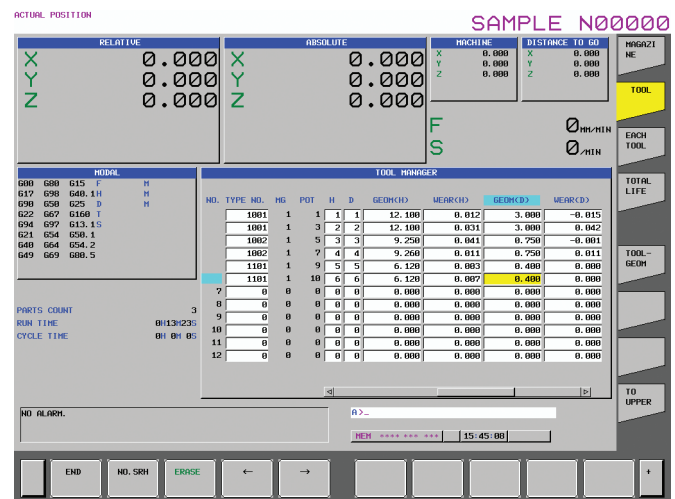
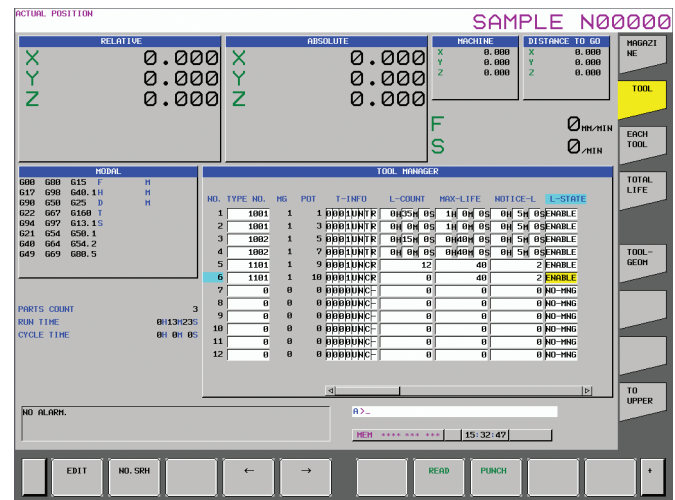
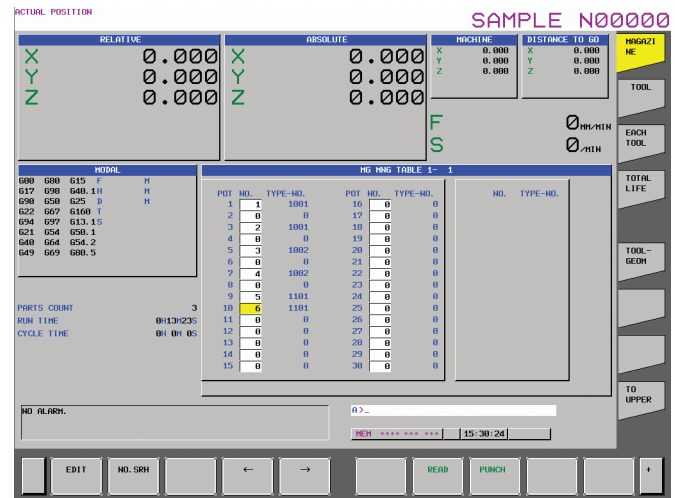
Tool life management can be used to implement a standardized tool life policy. When tools are installed in the machine, the tool life can be established in terms of time or usage. When the tool life limit is reached, the operator can be alerted to perform tool maintenance at a convenient stopping point. Custom Macro B statements can monitor offset values as they are adjusted. By comparing the new offset value with a maximum offset value, the operator can be notified if the tool needs to be changed due to excessive wear. Tool life policy values can be specified by the operator as new tools are loaded, or they can be specified in simple part program subroutines generated by the tool room, or on RFID tags. The actual tool life data can be monitored remotely via Ethernet, or it can be stored on RFID tags for analysis in the tool room.

A tool changer can also be loaded with multiple tools of the same type. Tool life management organizes tools of the same type into groups. The part programmer specifies the group in the part program rather than a specific pocket number. As a tool's life expires, the next tool in the same group is automatically selected by the CNC, extending the time between tool maintenance interventions.

Tool life management minimizes tooling costs by automating a tool change policy, eliminating the operator to operator variation. It eliminates unnecessary minor stoppages and therefore enables unmanned machining during breaks, lunches or complete shifts, or when an operator manages multiple machines. Since implementing tool life management may require some CNC-to-machine interface modifications, a retrofit is the ideal time to implement this valuable feature.

### Power monitoring

Extending tool life is an additional benefit of adaptive control, a phenomenon resulting from keeping a constant load on the tooling. This is particularly important when processing very hard materials, such as that machined in many aerospace and power generation applications. The power limits established by adaptive control can be used by the tool management system to specify one more dimension to check to avoid an unexpected broken tool.



# What to Consider when Retrofitting, Rebuilding or Remanufacturing Machine Tools

## Features for increasing setup and production part yield

Workpiece dimensional and surface finish defects may result from bad tooling, worn spindles or workpiece clamping, but the major causes of defects can usually be attributed to positioning errors in the machine tool itself. The typical 3-axis machine tool has numerous dimensions of potential inaccuracy. Each axis has defect opportunities in positioning accuracy, pitch, and yaw. Each pair of axes has defect opportunities for vertical straightness, horizontal straightness, and squareness.

Many errors can be fixed in minutes, once the source is determined. It does not matter if a machine is new or old -- they all have errors. The secret of defect-free production is to know the true capability of a machine tool and to apply appropriate adjustments and CNC features to improve positioning accuracy.

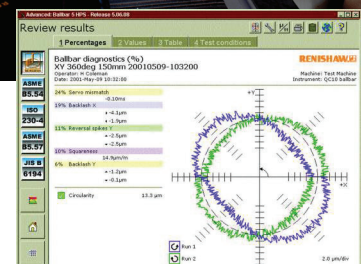
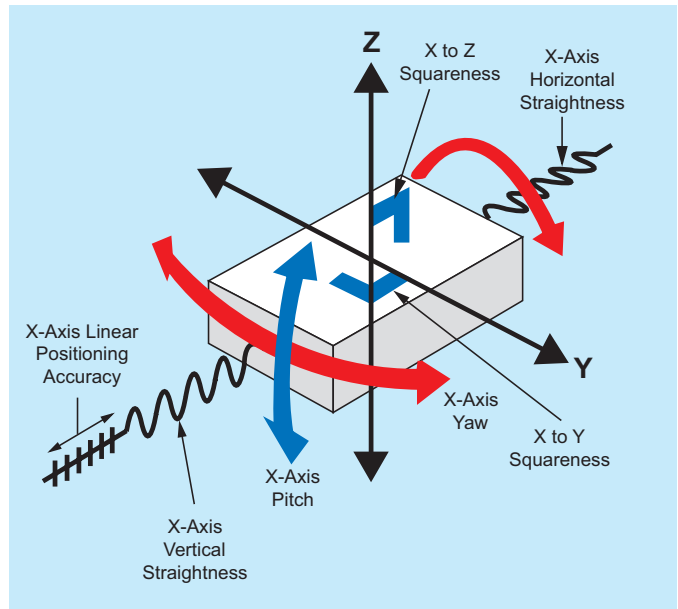
Improving the process capability of the machine reduces the need for part inspection to ensure part quality, and it reduces the potential for scrap. So, when retrofitting a CNC without rebuilding the machine mechanics, it is still a good time to improve the process capability of the machine.

### Ballbar analysis

A ballbar test is used to measure geometric errors present in a CNC machine tool and detect additional inaccuracies induced by the CNC and servo drive systems. Errors are measured by instructing the machine tool to scribe a circle. Small deviations in the radius of the circular path are measured by a sensitive transducer and captured by software. The data is then analyzed and plotted to reveal how well the machine followed the programmed path.

If the machine had no errors, the plotted data would describe a perfect circle. The presence of errors distorts the circle, for example, by adding peaks along its circumference and possibly making it elliptical. These deviations reveal problems and inaccuracies in the CNC, drive system servos and the machine's mechanics.

Each error is ranked according to its significance to the overall machine accuracy. Accuracy is graded with a value for circularity and positional tolerance. The system explains the likely causes for each type of error and offers advice on how best to fix them. Pinpointing specific faults enables efficient, targeted machine maintenance, which minimizes downtime. When the machine, CNC and servo systems are adjusted to the best of their abilities, the ballbar test data serves as a baseline benchmark for maintaining the level of process capability in the future.





### Compensations

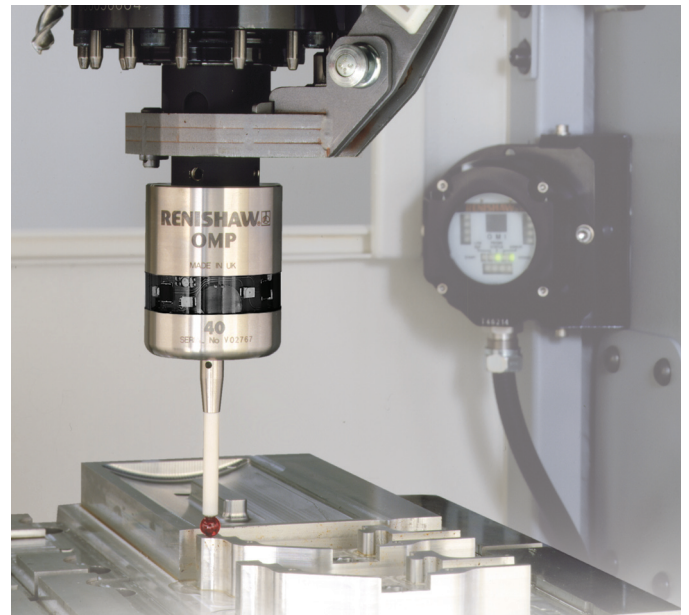
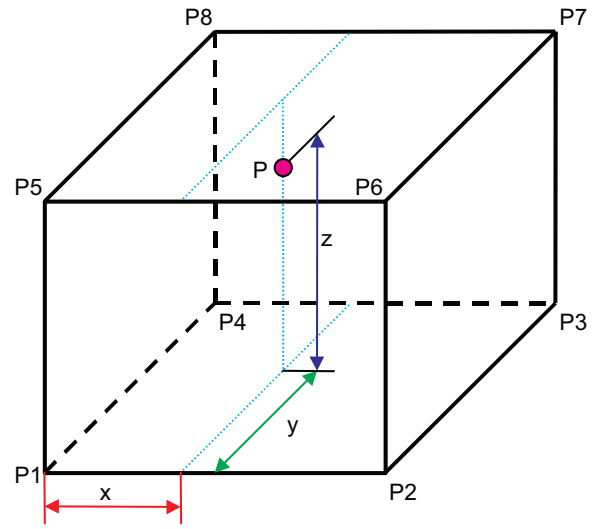
After using a ballbar test to adjust the machine mechanics to the best of their capabilities, the CNC can apply compensation factors to the errors that remain. Interpolated, bi-directional pitch error compensation can correct for manufacturing variation along the complete length of the ballscrew. Cyclical pitch error compensation can take out characteristic errors that occur for each revolution of a ballscrew, or it can be applied to rotary axes. Interpolated straightness compensation adjusts for linear deviations between two axes, while volumetric compensation can correct for positional errors in 3D space.

Most of these compensation tools required specialized laser measurement equipment and a skilled technician to establish the appropriate compensation values. The servo drive system also includes many parameters to compensate for issues such as backlash, backlash acceleration and overshoot, which can also be evaluated and set during a professional servo tuning.

### In-process gauging

Many manufacturers inspect parts to make sure that the bad ones do not get to their customers, and most take samples during a batch to check to see if tool wear offset adjustments are required. The operator stops the machine, measures the part, makes a calculation and updates a tool offset. This can be a prolonged and error-prone process. In some cases, an operator may make an adjustment based on a single sample, which can lead to what quality experts call “tampering”. If the operator is not dedicated to the one machine, it may sit waiting for attention when the part program stops the process for the inspection cycle.

Using a spindle probe or an automated inline gage station eliminates the dependency on an operator. It eliminates measurement variation between operators, and the potential for data-entry errors. Statistical Process Control (SPC) techniques can be used to update offsets to prevent the effects of tampering. By focusing on the process capability of a machine rather than inspecting the final part, fewer measurements need to be taken to ensure part quality, and the automation allows the process to run unmanned through breaks and entire shifts as required.





# What to Consider when Retrofitting, Rebuilding or Remanufacturing Machine Tools

## How to select a retrofit partner

North America has more than 250 retrofitters, ranging from one-person operations to companies with 50-employees or more. Many machine tool builders also specialize in retrofitting their own machines. There is obviously a cost impact of selecting a partner that is not local, but there could also be serious warranty issues if the company is no longer around when you need assistance.

Machine tool builders and retrofitters often specialize in certain kinds of machines. So when choosing a retrofitter, it is important to make sure that they have competencies related to your particular type and model of machine. Ask for references and confirm the quality of the work performed and determine how long the machine was out of commission during the retrofit.

It pays to get multiple quotes for any significant investment, and compare them for discrepancies to uncover any lack of core competencies. Make sure you are comparing apples-to-apples on everything, including the CNC features, the work to be performed, and the length and terms of the warranty. Document everything related to the scope of work to ensure a common understanding for a long term, win-win relationship.

Check the availability and quality of the documentation that will be provided with your retrofit, including wiring diagrams, and the machine, CNC, servo and spindle drive manuals. The documentation set needs to cover, operation, programming and maintenance.

Look for pre-engineered kits from machine tool builders, retrofitters and control manufacturers. It is not uncommon for a company to provide kits for a high-volume machine tool with a good brand name that is common in the industry. These kits typically include everything necessary to complete the retrofit of the machine onsite, amortizing the engineering costs over multiple installations, so they should cost less than a custom retrofit.

GE Fanuc has close relationships with most of the industry's leading retrofitters and can help you find multiple companies with experience with a specific machine tool.

## Justifying a retrofit

Justifying a retrofit is the same as justifying any other high-value investment. A return on investment will occur when a business spends money to increase revenue, decrease or avoid costs. Performing an ROI analysis will document the value a company will lose if they decide not to invest in or defers an investment to retrofit, rebuild or remanufacture a machine tool.

First, list all the potential revenue improvements from the extra capacity and throughput from the machine. Consider all the categories of setup reduction, downtime improvement, speed improvement, minor stoppage reduction and increased setup and production part yields. Factor any savings from automation, including reduced labor, and the ability to run unmanned through breaks and additional shifts. Consider that the typical machine tool is only utilized at 30 to 40 percent of its capacity. Applying lean CNC technologies can significantly improve this percentage.

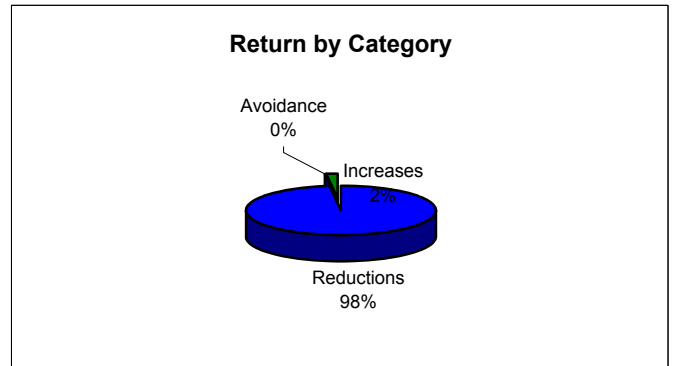
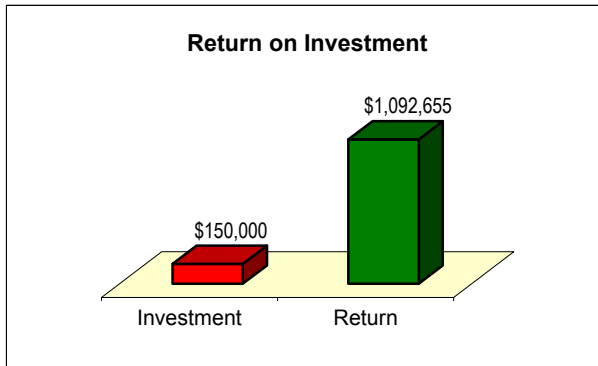
Secondly, list all the costs for the retrofit from the quotations received.

Finally, perform the standard return on investment and payback calculations.

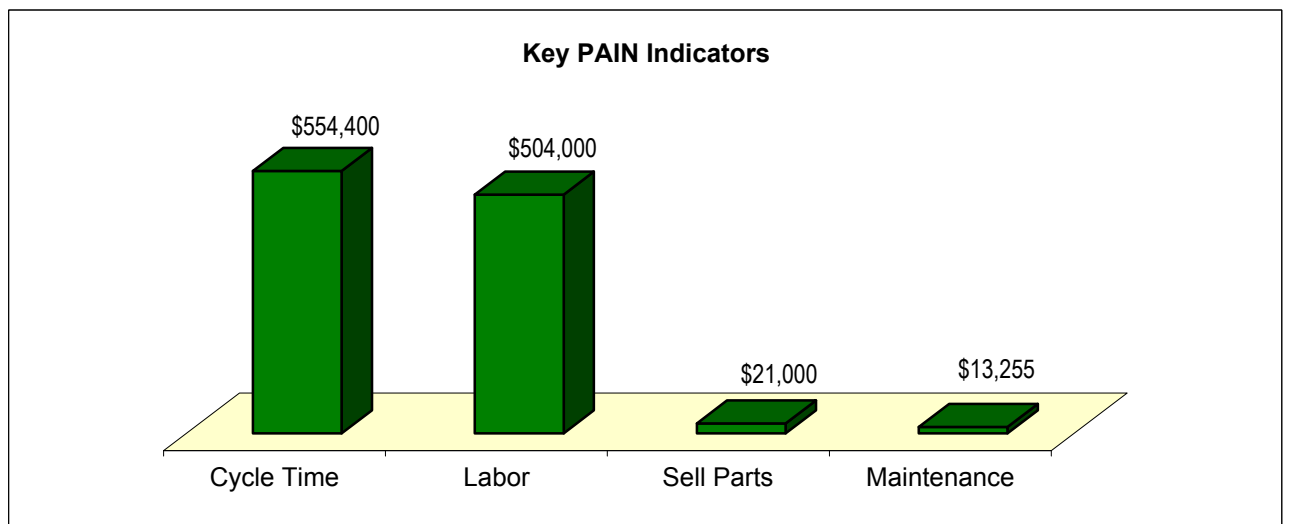
Financial analysis is at the heart of most important investment decisions, but it is also important to list any additional non-financial benefits, as they can be used as tie-breakers between investments of similar value. Particularly list any benefits that support your company's current initiatives, such as Lean Manufacturing, Total Productive Maintenance or other continuous improvement programs.

## Return on Investment Financial Dashboard

### Example Retrofit Project



Financial Dashboard Summary		Year 1	Year 2	Year 3	Total
ROI Investment:		\$150,000			\$150,000
Savings from Cost Reductions:		\$330,985	\$370,585	\$370,085	\$1,071,655
Savings from Cost Avoidance:		\$0	\$0	\$0	\$0
Savings from Revenue Increases:		\$21,000	\$0	\$0	\$21,000
Estimated Savings: -\$150,000		\$351,985	\$370,585	\$370,085	\$1,092,655
Financial Dashboard Summary Metrics					
Return on Investment Percentage:		728%			
Payback Period (Months)		5			
Factor:	<div>8.0%</div>	Net Present Value:	\$937,414		
Internal Rate of Return:		232%			
Key PAIN Indicators		Year 1	Year 2	Year 3	Total
Reduced part cycle time:		\$158,400	\$198,000	\$198,000	\$554,400
Reduced labor costs:		\$168,000	\$168,000	\$168,000	\$504,000
Reduced CNC parts inventory:		\$21,000	\$0	\$0	\$21,000
Reduced CNC mainenance costs:		\$4,585	\$4,585	\$4,085	\$13,255
Total value estimation from KPIs:		\$351,985	\$370,585	\$370,085	\$1,092,655



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# What to Consider when Retrofitting, Rebuilding or Remanufacturing Machine Tools

## Summary

Retrofitting is typically a low-cost alternative to purchasing a new machine tool. It will improve mean-time between failures and mean-time to repair. Additional benefits can be realized in energy savings, performance improvement and improve access to manufacturing data.

There are many features that can be included in the new CNC to support Lean Manufacturing, reduce setup time, downtime and minor stoppages, and increase speed, setup part yields and production part yields. The downtime that is inherent when the CNC is being recommissioned is an ideal time for training, changing processes and taking advantage of professional services that can make the project a complete success.

By selecting the right retrofit partner and by producing a credible investment justification, you can be assured that a retrofit will deliver the promised return on investment.

## GE Fanuc Intelligent Platforms Information Centers

Americas:  
1-800-GE FANUC or (434) 978-5100

Asia Pacific:  
86-21-3222-4555

Europe, Middle East and Africa:  
(352) 26722-1

Europe, Middle East and Africa (CNC):  
(352) 727979-1

## Additional Resources

For more information, please visit  
the GE Fanuc web site at:

[www.gefanuc.com/cnc](http://www.gefanuc.com/cnc)

