THE DIGITAL JOURNEY OF THE MODERN MACHINE SHOP

REPORTING FINDINGS FROM THE NC MACHINING STUDY

LIFECYCLE INSIGHTS

INTRODUCTION

Running a machine shop in today's economic environment is no easy task. The margins are razor thin. Competition for a job might be located across town or across the ocean. Customers demand top quality yet require delivery on incredibly short schedules. The opportunities are there, but it takes highly skilled organizations to profit from them.

It is in this context that Lifecycle Insights conducted our 2017 NC Machining Research Study. Findings indicated that the dominant driver for any attempts to improve operations is *Time-to-Delivery*. However, a myriad of technical challenges undermines those efforts, ranging from high friction in the process of working with models, debilitating difficulty in creating toolpaths, unreliable verification of G-code, and low reuse levels of machining knowledge.

Fortunately, many of these challenges can be addressed with the digital journey of the modern machine shop. The technologies that enable this digital journey allow machinists to seamlessly prepare and manipulate models from any CAD application, develop high quality toolpaths in an automated fashion, simulate the execution of the resulting G-code, and standardize NC knowledge for reuse across the entire process.

The purpose of this eBook is to dive deeper into these issues. First, this publication formally publishes and contextualizes the NC Machining study findings. Next, it introduces an ecosystem of technologies that address the needs of modern machine shops. Last, it offers recommendations for next steps.

There are many challenges in running a machine shop. However, use of the right technologies can make it easier and more profitable.

TIMELY DELIVERY IS THE TOP ISSUE FOR MACHINE SHOPS

Machine shops, like many companies participating in the development process, are often under pressure to improve their operations. Respondents to this study were no different.

Time-to-Delivery stood out as the single most important driver of change for machine shops, overshadowing the next closest answer by nearly two-to-one. This finding, along with the other drivers for change, deserves a closer look, as this stands as a goal or objective for these companies.

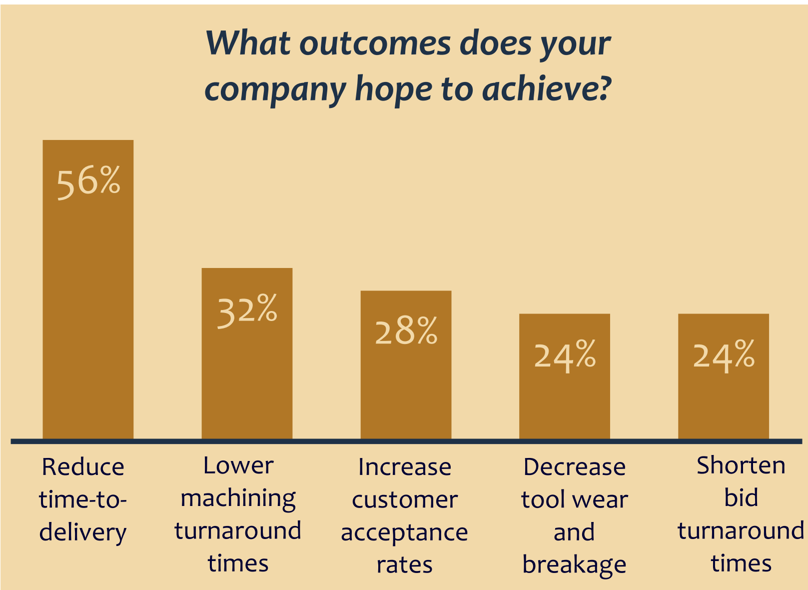


Figure 1: Top Goals for Machine Shops
2017 NC Machining Study, Lifecycle Insights, 215 Respondents

TIME TO DELIVERY IS THE DOMINANT ISSUE

Many of the answers to this question in the survey are related to time. However, the most frequently selected option was *Time-to-Delivery*, or the measure of time between taking an order and delivering the order to the customer.

Why was this answer selected so frequently? Time-to-Delivery represents one of the most tangible financial measures for machine shops. Once delivered, the company can then invoice for the remaining monetary value of the order, making it tantamount to *Time-to-Invoice*. The more quickly the company can deliver parts, the sooner they can invoice and, ultimately, get paid. For smaller companies, cash-on-hand and cash flow are two of the most important metrics, representing their ability to honor debts, pay their employees, and remain financially viable.

Reducing *Time-to-Delivery* has some critical implications for machine shops beyond good fiscal health. It represents a desirable means of growing revenue. If a company can reduce delivery time, they can complete more jobs in a given timeframe, whether that be a month or a year, which translates to more revenue. Furthermore, they can accomplish this without purchasing more equipment to increase machining capacity, which requires a capital expenditure. As such, reducing Time-to-Delivery lets the company increase their top line (revenue) while maintaining or only minimally increasing their bottom line (costs, both initial and recurring). That turns into margin growth.

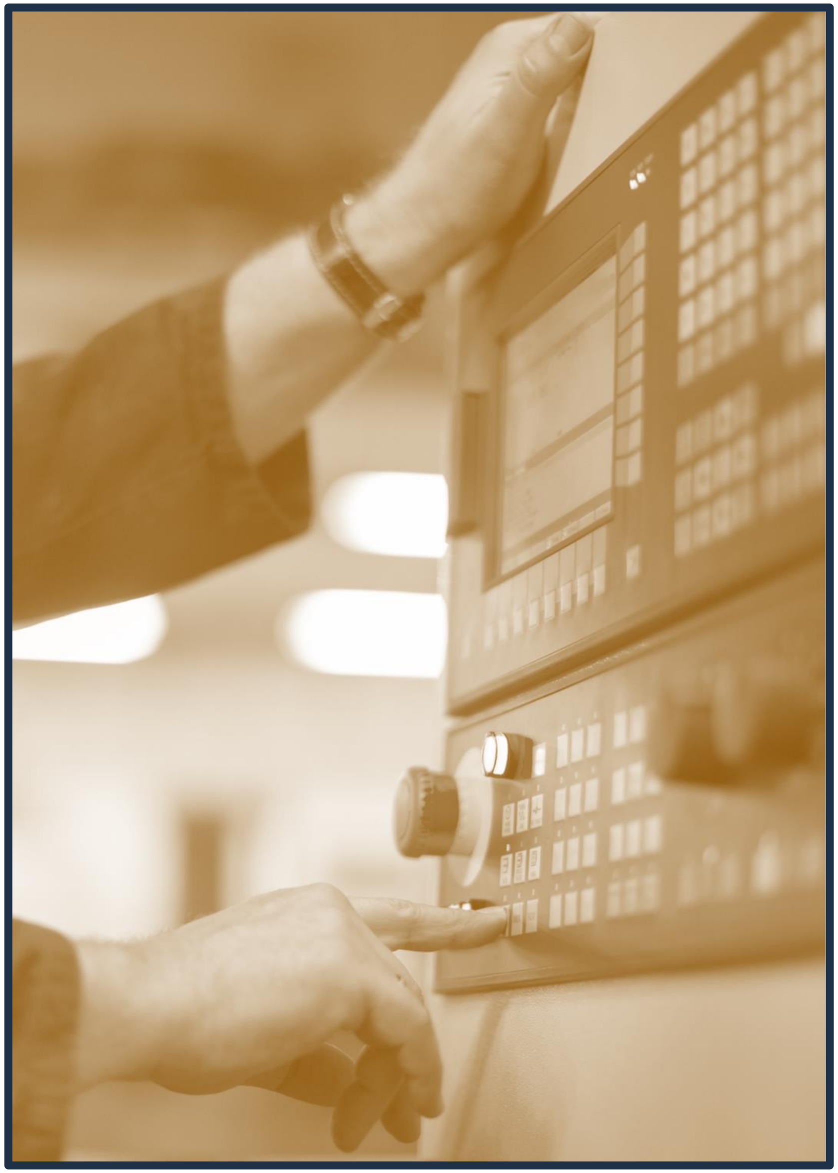
TOOL BREAKAGE AND TURNAROUND TIMES

Efforts to *Decrease Tool Wear and Breakage* carries cost savings implications for machine shops. However, there are other ramifications, as well. For instance, unexpected tool breakage can result in a significant delay in *Time-to-Delivery*. Unexpected tool wear can force shops into a lot of manual post-machining quality work, which can also delay delivery.

Lowering Machining Times is a measure that contributes to *Time-to-Delivery* as well. Depending on the type of machining work, this can be the longest period of the overall process. Shortening this measure can reduce *Time-to-Delivery*.

INCREASING ACCEPTANCE

Increasing Customer Acceptance Rates isn't a time oriented outcome, but it certainly is fiscally related. Parts that don't pass quality measures are returned to the machine shop. There, they must either be reconditioned so they meet customer requirements, which delays *Time-to-Delivery*, or they must be scrapped. If they must be thrown away, replacement parts must be machined using new raw materials, a process that increases the cost of the order without a corresponding increase in revenue. That, in turn, eats into the profitability of the job. Beyond the implications of getting a full order of parts to the customer, some contracts have financial penalties for exceeding certain return thresholds. All in all, there are many fiscal implications for *Increasing Customer Acceptance Rates*.



THE TOP TIME-WASTING ISSUES FOR MACHINE SHOPS

Time-to-Delivery is the dominant issue driving machine shops to improve their operations. If they can reduce this measure, they stand to increase revenues without dramatically increasing their costs, resulting in sizeable gains in profits. What barriers and challenges might stand in the way of achieving this goal? Answering that question is another function of the NC Machining Research Study.

One section of the survey presented respondents with a list of machining challenges and asked that they select the three they felt were most critical to them. Much like the high-level actions in this study, no single challenge distinguished itself from the others, with none exceeding 30%. This is representative of the many disparate issues that machine shops face in the order-to-delivery process. Nevertheless, these issues do coalesce around common themes.

FRICTION IN MODEL IMPORT, PREP, AND CHANGE

One set of issues that make it difficult to reduce *Time-to-Delivery* relates to friction and inefficiency, both digitally and physically, when going from a design to machined part. This includes:

- *Data must be transferred between different software (CAD, CAM, CMM) and teams*
- *Difficult to work with design and tooling models from customers*
- *Painful to accommodate design changes from internal or external stakeholders*

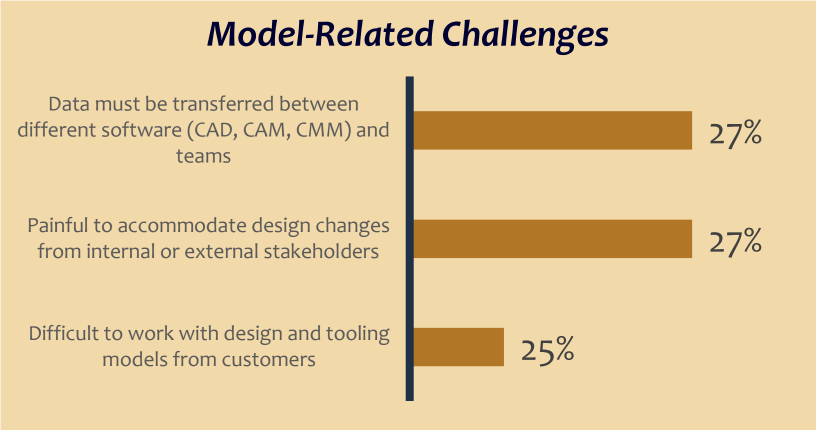


Figure 2: Top Three Machining Challenges: Model-Related
2017 NC Machining Study, Lifecycle Insights, 215 Respondents

Importing models and getting good geometry continues to be a challenge for many groups in the development. However, machinists face the additional challenge of making changes to such models in preparation of toolpath creation. This often includes changes to geometry so it is not difficult or costly to manufacture. Yet when a model is imported, the features and parameters used to create that geometry have been stripped away. The result is solid geometry without any controls. Modifying such a model is time-consuming and painstaking.

Another issue lies in design changes. At design release, the model is supposed to be finalized. However, many organizations identify issues with the design after it has been released requiring geometry modifications and a rerelease. Since more than 50% of machine shops rely on standalone CAD and CAM systems, making design changes forces them to repeat this entire process, starting with re-importing the model, fixing it, and then re-preparing it for machining. This process also undermines the concept of concurrent development, where machinists can start laying out toolpaths while engineers are designing the components.

Lastly, working through exporting and importing geometry issues isn't just a problem when dealing with files from a customer. Many machine shops have a wide array of CAD, CAM, and CMM software applications. Running a job may require toolpaths from the CAM software and then inspection paths from the CMM software. Considering that about 75% of machine shops use disconnected CMM inspection processes, a large majority of the organizations end up translating geometry between these systems within their own company, thereby contributing to the geometry translation issue.

In all, these issues represent a major hurdle in terms of reducing time to delivery.

DIFFICULTY IN CREATING GOOD TOOLPATHS

Other issues that make it difficult to reduce *Time-to-Delivery* exist in terms of the digital development of toolpaths in software applications. These include:

- *Generating good toolpaths is difficult due to part model prep, many toolpaths iterations, editing, etc.*
- *Machine operations are inefficient due to air cutting, low material removal rate, tool overload, chatter, etc.*
- *Machined parts require rework (quality, surface finish, aesthetics, etc.) to meet requirement*
- *Use of paper-based documentation on the shop floor*

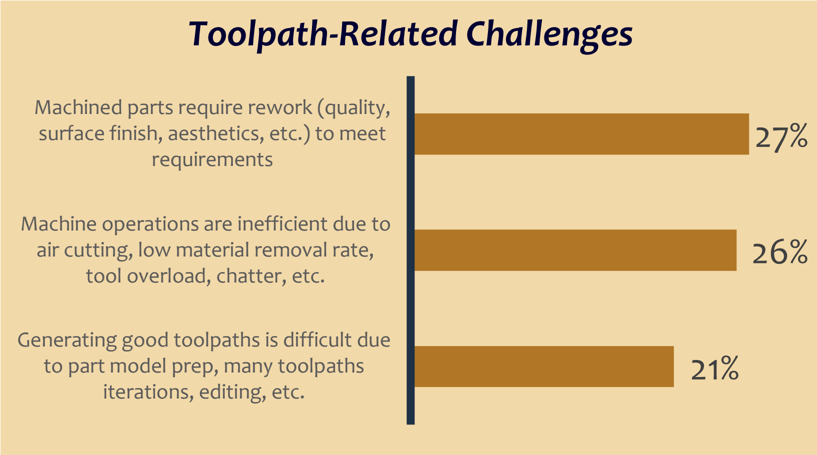


Figure 3: Top Three Machining Challenges: Toolpath-Related
2017 NC Machining Study, Lifecycle Insights, 215 Respondents

Creating a toolpath is rarely simple. There are a variety of complicating matters, including model import and cleanup. However, developing a good toolpath often requires careful crafting to ensure that it will accomplish the desired effect, at least as planned. A number of companies, however, find that they cannot rely entirely on their CAM software to generate toolpaths reliably. Some 21% of the respondents from this study manually modify their toolpaths in their CAM software applications on a daily basis.

Many issues can come to life when you start to cut metal. Developing a feasible toolpath often is not enough. Machine shops need efficient toolpaths to reduce *Time-to-Delivery*. The problems here vary widely. Some toolpaths might include moves where little or no material is being cut. Some toolpaths might remove too much material or result in chatter. The result is that a number of components need to be manually reworked to meet the original requirements from the customer. An amazing 24% of the respondents from this study performed unplanned polishing to parts to achieve the desired surface finish on a daily basis. These are yet more issues that prevent shops from reducing time to delivery.

These three issues are especially true when developing toolpaths for High Speed Machining. Toolpaths for such machining must actually take the sizeable momentum of the cutting tool and equipment into account when making CNC moves. A number of shops, including 67% of the respondents of this study, are adopting the usage of such cutting strategies because they reduce the turnaround times of jobs. The toolpath issues identified so far, however, are only exacerbated in high speed machining. However, to use such machining strategies effectively, the right toolpaths must be developed.

A surprising 61% of machine shops transfer critical manufacturing documentation (setup sheets, tool lists, and setup drawings) to the shop floor using paper. This only makes it more challenging to use standardized and flexible cutting methods to drive machine tools efficiently.

UNRELIABLE VIRTUAL VERIFICATION OF G-CODE

Making sure that G-code, the equipment specific version of a toolpath, runs as expected is a key step before cutting metal. Many companies work on verifying their G-code virtually as a simulation, which eliminates the risk of breaking tools, work materials, or the machining equipment. However, for some companies, this is problematic. These issues include:

- *Machine tool often behaves differently than simulation in CAM software*
- *Need to manually validate the NC programs (G-code)*

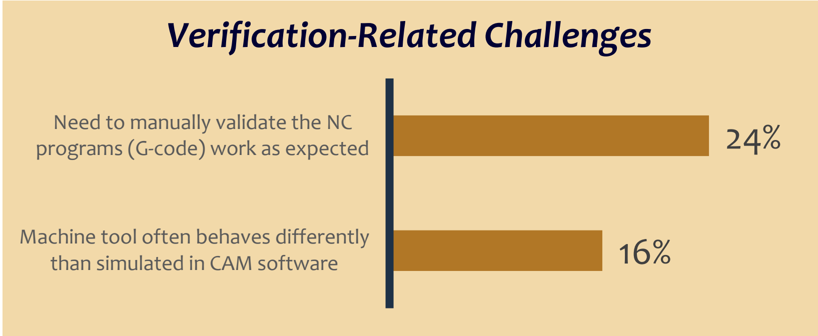


Figure 4: Top Three Machining Challenges: Verification-Related 2017 NC Machining Study, Lifecycle Insights, 215 Respondents

However, simulations in CAM applications may not catch all of the problems associated with the toolpath because the digital verification is rarely based on the post-processed G-code that actually drives the CNC machine. When virtual verification using CAM applications cannot reliably catch such issues, the company must *manually* review the G-code that includes the instructions for the CNC machine. This is done by reviewing the text of the G-code, line by line.

Manually reviewing G-code is a time-consuming and painstaking activity that can delay *Time-to-Delivery*. Note that this is no small problem. A full 27% of all respondents to this study manually modify G-code on a daily basis. Furthermore, manual reviews do not eliminate every single problem in the physical world. Some 32% of the respondents experienced a tool to part clash on a weekly basis.

OPPORTUNITIES FOR NEW TECHNOLOGIES

There are many challenges to reducing *Time-to-Delivery* for machine shops. However, these companies need not only worry about risks. There are numerous opportunities that offer a means to shorten *Time-to-Delivery* as well.

LEVERAGING 3D PRINTING FOR PRODUCTION

The explosion of 3D printing has provided a buzz of excitement for makers in recent years. Many forecast a day when production parts can be simply printed in a matter of an hour instead of cutting metal over the course of a day. Interestingly, findings from the study show that the future is closer than forecasted.

- 37% of respondents use 3D printing on experimental jobs
- 25% of respondents use 3D printing on select jobs
- 12% of respondents use 3D printing on mainstream jobs

The impact on *Time-to-Delivery* is compelling. Printing parts can be faster than cutting metal, which shortens the time it takes to deliver those parts. There are other implications, as well. Using 3D printing, manufacturers can drastically reduce the number of operations, setups, and machines required, and this reduces time and cost that contributes to a reduced *Time-to-Delivery*. Furthermore, 3D printing helps manufacturers produce complex parts that were impossible to make before.

Lastly, the simple act of building up a component out of material instead of cutting away material has cost implications. With 3D printing, there is little to no waste, as the leftover material can be used on the next job. With machining, the metal shavings can be recycled, but cannot be readily reused. Leveraging 3D printing instead of subtractive manufacturing methods is an opportunity to boost profit as well.

EMPLOYING ROBOTIC TENDING AND MACHINING

Another technology that some manufacturers are beginning to embrace is machine tending and machining using robots. Findings from the study show that 24% of respondents are currently using robotics for machine tending and CNC machining. These capabilities have traditionally automated production tasks like lifting, positioning, and welding. However, robots are now being fitted with tool-holding heads so they can perform operations like trimming, polishing, and deburring.

Applying traditional and progressive applications of robotics in machining increases automation, allows for consistency in quality, enables bigger parts to be machined in a single setup, and extends operating hours. A key to productively using robotics is leveraging a CAM application that can support such programming tasks.

USING THE IIOT FOR MANUFACTURING INSIGHT

Another emerging trend comes with the Industrial Internet of Things (IIoT), where sensors and intelligent software are applied to the shop floor. The idea here is to capture data from machining centers and other production equipment and analyze it to identify anomalies such as quality issues or machine errors. Once identified, corrective action can be taken to mitigate such issues. Some 29% of the respondents from the study use Machine Data Acquisition (MDA) from controllers or sensors attached to a machine.

STANDARDIZATION, DATA CONTROL AND REUSE

An opportunity to reduce *Time-to-Delivery* exists in the standardization, data control, and reuse of NC knowledge in the organization. The idea is to codify machine settings, such as feeds, speeds, stepover values and other information, from job to job. In theory, this should reduce the preparation required to develop a toolpath and generate G-code. Findings from the study show that some 39% of organizations are pursing this kind of standardization and reuse effort. While progressive manufacturers implement processes to store, classify and re-use knowledge, fewer than 30% of machine shops manage and control their data.

Employing standardization and reuse to machining is especially applicable in the light of *Time-to-Delivery* and delivering high quality parts. Vetting good practices and spreading their use across the machine shop allows all machinists to reap gains. Furthermore, it means that individuals don't have to reinvent the wheel, developing their own methodologies to create good processes. In all, leveraging standardization and reuse allows for higher quality in less time.

INTEGRATED MACHINING ECOSYSTEMS

When it comes to reducing *Time-to-Delivery*, machine shops are faced with a range of challenges as well as opportunities. Overcoming these barriers or pursuing these chances to improve are closely connected to the technologies used to execute the order to delivery process. Interestingly, a strong case exists for an integrated set of software applications that work together as a single IT ecosystem.

POWERFUL CAD TOOLS FOR IMPORTED GEOMETRY

As noted earlier, machine shops must work with design models from a variety of sources. In this context, it is important to have Parametric, Direct, and Facet Modeling capabilities.

Parametric Modeling provides powerful features and dimensional controls over geometry. By enabling users to embed intelligence into the model, it allows creation of toolpaths and inspection paths based on a few simple inputs. Direct Modeling allows users to push, pull, and drag geometry without needing to know how the model was built. This is an ideal application to prepare imported geometry for machining. Facet Modeling allows users to modify mesh geometry, the result of laser scanning, STL export, and topology optimization. Most notably, it lets organizations avoid the painful process of converting mesh geometry into boundary representation geometry before making changes.

These capabilities directly address the issues related to friction in the model import, prep, and change process cited earlier in this eBook. By eliminating these issues, machine shops can reduce their *Time-to-Delivery*.

INTEGRATED CAD-CAM-CMM SOFTWARE SUITES

Another major challenge machine shops must overcome is the need to work with a model in a CAD environment, a CAM environment, and a CMM environment. Suites of integrated CAD-CAM-CMM software applications utilize a single model instead of translating them back and forth. By leveraging a single software application instead of several, users can eliminate myriad geometry translation issues. As a result, engineers, machinists, and quality inspectors work in a single environment where they can design, import and fix geometry, develop and export toolpaths for NC equipment as well as inspection paths for CMM machines. This significantly reduces the amount of friction in the digital process.

MODEL-DRIVEN MACHINING PROCESS

Another issue confronting machine shops is the need to accommodate design changes from engineers and customers. A notable approach to this problem is the Master Model method (or model-driven process). This allows the machinist to create a derived version of the 3D model from the engineer. That model can then be modified and tweaked so it can be prepared for the development of toolpaths. Then, when a change is made to the original design, it propagates to the derived models, including the machining and inspection models. This means the toolpaths and inspection paths are then updated in an automated yet safe way.

PROGRAMMING PRODUCTIVITY AND AUTOMATION

The *automated* development of good toolpaths is a definite challenge for machine shops. They take too long and are error prone, requiring manual modification. However, new capabilities of modern CAM software applications offer a means to mitigate this issue. Feature-based Machining allows NC programmers to automatically create toolpaths for a large number of intelligent machining operations. Such machining features can react to modifications in a variety of ways and are more resilient. They provide an automated means to create high quality toolpaths that eliminate some, if not all, of the manual effort associated with NC programming.

MANAGING MANUFACTURING MODELS AND DATA

The transition from design to cutting metal creates a trail of important digital artifacts. The design model is used to create a manufacturing model, which may be tweaked and modified for production. That manufacturing model is used to create setup drawings, setup sheets, tool lists, toolpaths, and inspection instructions. All of these digital deliverables are used during the manufacturing process. Changes might need to be made anywhere along this digital chain of artifacts. It is critical to manage such change; otherwise, the wrong information could be used to cut metal, resulting in scrap and delays.

Managing all of these artifacts and providing access to a single source of truth is the purpose of Product Data management (PDM) solutions. These technologies manage the relationships between deliverables, notifying the appropriate stakeholders of changes, and ensure that the correct version of those deliverables is used during each stage of the process.

One enticing aspect of an integrated machining ecosystem is that the entire team can access a single source of truth. Engineers can be sure they are working on the latest model revision, and NC programmers use the released part models for toolpath development. Moreover, closing that loop also provides other exciting advantages. Machinists can store the machining models where they have made modifications in the same system, creating a historical record of the changes to the design required before final production. Capturing that knowledge is crucial to making better decisions going forward.

Another opportunity exists in capturing quality information. All sorts of manufacturing execution and quality system data can be connected to the design and machining models, closing the loop on the design changes. In all, managing all of the artifacts in the order-to-delivery process allows everyone to access a single source of truth, eliminating costly errors and delays. It also creates a historical record that feeds information back to the engineers.

SUMMARY AND CONCLUSION

Per Lifecycle Insights' NC Machining study, reducing *Time-to-Delivery* is the top objective for today's machine shops. Achieving this goal translates into increased revenue, since more jobs can be completed while maintaining similar costs.

CHALLENGES TO REDUCE TIME-TO-DELIVERY

However, shortening *Time-to-Delivery* is no easy task. Myriad challenges oppose such an objective, including:

- ***Friction in Model Import, Prep, and Change*** workflow makes it difficult to initially prepare a model for toolpaths and to accept design changes late in the process
- ***Difficulty in Creating Good Toolpaths*** results in many iterations of toolpaths, manual effort to modify them, and manually finishing machined parts
- ***Unreliable Virtual Verification of G-Code*** means more manual work must be invested in the review of the text-based machine code

OPPORTUNITIES TO REDUCE TIME-TO-DELIVERY

In addition to those machining challenges, machine shops can pursue opportunities to achieve their objective, including:

- ***Leveraging 3D Printing for Production*** provides a means to produce and deliver parts faster at lower cost
- ***Employing Robotic Tending and Machining*** provides automation that enables higher quality and flexibility
- ***Using the IIoT for Manufacturing Insight*** streams data off machining equipment, offering visibility for improvement
- ***Standardization, Data Control and Reuse*** accelerates the development of good and reliable toolpaths

INTEGRATED MACHINING ECOSYSTEMS

New technologies, particularly an integrated machining ecosystem of software applications, offer a means to address the challenges and opportunities to reducing *Time-to-Delivery*.

- ***Powerful CAD Tools for Imported Geometry*** put the right capabilities in the hands of machinists to prepare models
- ***Integrated CAD-CAM-CMM Software Suites*** reduce the need to translate models with the company
- A ***Model-driven Machining Process*** allows machinists to do their work without fear of design changes
- ***Programming Productivity and Automation*** leverages smart feature-based toolpaths that can adapt to change
- ***Managing Manufacturing Models and Data*** provides a secure vault to host a single source of truth for design models, manufacturing models and much more

Running a machine shop today is no easy task. However, with the right technologies, it can be far easier as well as profitable.

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LIFECYCLE AND DEMOGRAPHICS OF THE NC MACHINING STUDY

THE NC MACHINING STUDY

The NC Machining Study researched the business priorities as well as the tactical practices and technologies of modern machine shops.

Between September and October 2016, Lifecycle Insights surveyed 215 respondents to assess the strategies and tactics being employed in modern machine shops, specifically focusing on their business objectives, common practices, and technologies deployed.

The number of respondents to the survey totaled 215. However, the findings of this study are based on a subset of these respondents, totaling 177, that excludes software providers, service providers, and system integrators.

Respondents to the study's survey serve a wide variety of industries. The industries served at the highest rates by the survey respondents include: 48% Aerospace and Defense, 24% Industrial Machinery, 24% Automotive, 23% High Tech, Electronics and Consumer Products, 19% Energy Equipment (Oil and Gas), and 18% Construction, Agricultural or Heavy Machinery. Note that respondents were not limited to selecting one industry, as suppliers often serve multiple industries.

These respondents are employed at companies with a wide range of revenues, including: 74% from companies with less than $100 million in revenues, 15% from companies with revenues between $100 million and $1 billion in revenues, and 11% from companies with revenues more than $1 billion.