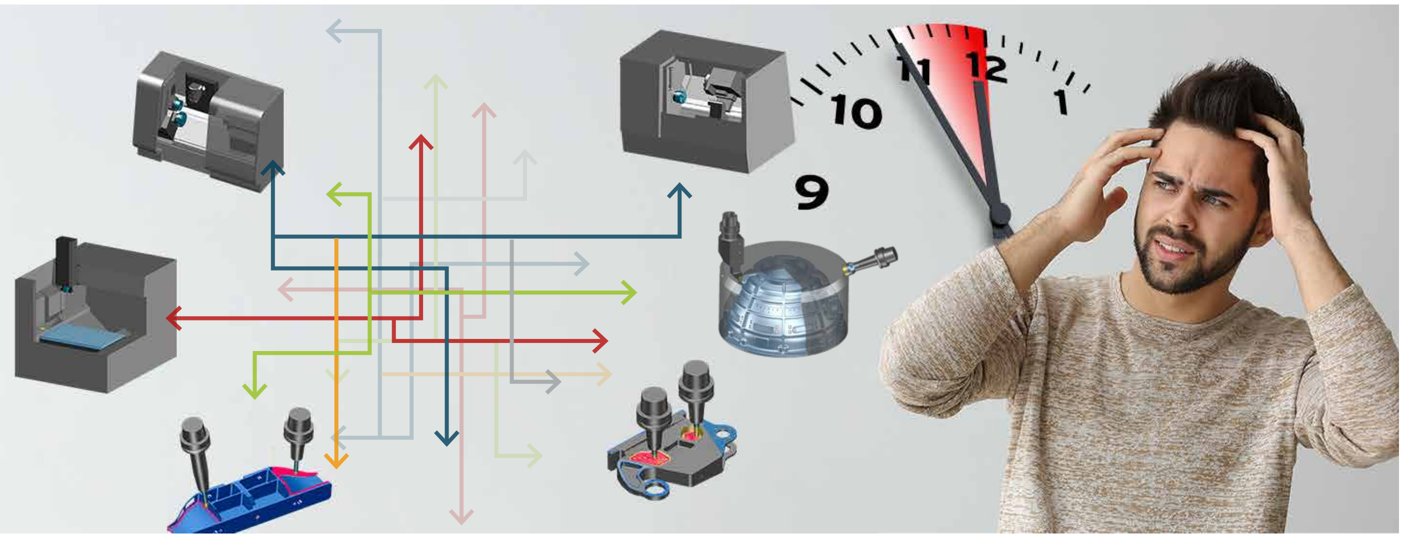
More clarity in manufacturing

How to implement digital solutions with your existing resources and quickly improve efficiency

1 A revolution in manufacturing

In production machining and systems manufacturing—and particularly in the world of single-part and small-series manufacturing—complexity is continuously increasing. Workpieces, milling tools, machine tools and machining methods are rapidly evolving. At the same time, the requirements for planning, control, and optimization of production processes are always on the rise. The result is a shifting web of interlocking constraints that is increasingly difficult to comprehend, even as an overall construct.



Something's not right here! Typical manufacturing pain points

Organizational structures and processes that have previously excelled have now become obsolete during the digital transformation. These common pain points felt in all areas of the production chain suggest that changes need to be made:

Factory floor

- Machine idle times are too high.
- Machines are not optimally utilized (machine and manufacturing tasks do not align).
- Machining takes too long.
- Damage to the machines causes production delays.

CAM programming

- CAM programming generally takes too long.
- Quality of results and work required vary widely, even for similar tasks.

Expertise

- Not enough qualified personnel are available to do the work.
- The few experienced workers are spread thin on too many projects.
- Company knowledge is not captured or transferred properly.

Logistics

- Deadlines are missed.
- Material not available on time, plus missing clamping devices, tools, NC information etc.
- Responses to fluctuating order quantities and new requirements are too slow.

Market position

- Dependence on a single industry or a small number of customers is too great.
- Too much focus on specializing in a narrow range of components.

Even though many manufacturers are experiencing these issues, they usually will not spend the time or money to initiate process changes or updates. As long as the order books are full, "if it ain't broke, don't fix it" mentality dominates. Improvements are generally cosmetic and have only short-term effects.
But what will companies do if the production machining market situation changes dramatically, as it has in Germany (see Production machining: Current situation)?

Production machining: Current situation

Production machining, one of the most important pillars of the German economy, especially in single part and small series production, continues to face major challenges following the gradual decline in pandemic-related restrictions. Just to mention two challenges: Lack of qualified personnel and supply chain issues.
According to a survey published by the German Engineering Federation (VDMA) in June 2021, 82% of respondents are currently experiencing a slight to severe lack of qualified personnel. Furthermore, 43% of the companies expect the situation to intensify. At the same time, 77% of the companies surveyed are planning to hire more people. This clearly shows that there is still a huge need for qualified personnel.[1]
In another survey of 574 companies by the VDMA in September 2021, 81% of production machining companies report significant or serious impairment of their supply chains. This has nearly doubled from the second quarter of 2020 at the start of the pandemic.[2]
Digitization is also a challenge. According to a study by the German Federal Ministry for Economic Affairs and Energy, companies are using digitalization to pursue three main goals: strengthening their existing core business, developing new markets and business areas and developing knowledge and innovative activities.[3]

[1] Shortage of skilled personnel worsens again, 6/11/2021
[2] 11th VDMA Flash Survey – Results, 9/15/2021
[3] Successfully Implementing Digital Transformation, March 2020 (in German)

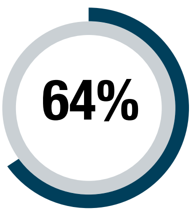
2 Digital solutions are inevitable

We all know that pain points will keep returning until the root cause is either eliminated or permanently fixed. Companies in the manufacturing industry who wish to remain competitive or be better than other companies must confront these challenges using digital and automated solutions.

Overwhelmed by digitalization?

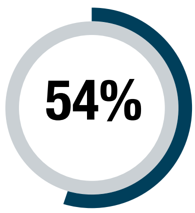
The industry recognizes the urgency to go digital, however, it can be very overwhelming at times for some small or medium sized companies who still may be performing programming on their machines. There are new concepts on the market every day, addressing virtualization, networking, the digital part, sensors, digital business models—the list could go on. With almost endless possibilities, digitalization might appear to be even more complex than the manufacturing world itself. Lack of expert knowledge, money and resources can make establishing a clear digitalization strategy seem near impossible.

This conflicted viewpoint was confirmed by a survey of more than 80 managing directors in the German manufacturing industry that was conducted by Tebis Consulting in April 2021:

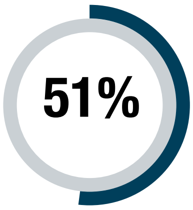


Up to **64%** of the companies target aspects of digitization, such as “planning and control”, “standardization” or “automation,” to optimize their processes.

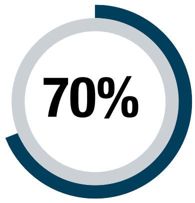
50% consider it necessary to reduce their lead times by at least 15% by the end of 2022.



54% have the opinion that they must increase their efficiency by at least 10% to remain competitive.



51% of the companies indicate that their sales prices have gone down by more then 10% (up to 20%) over the past 3 years.



Overall, **70%** categorize the current market situation as critical or even extremely critical. And only 15% expect a relaxation in sales prices over the next 12 months.

The complete survey report "Market Situation and Future Developments in Die, Model and Mold Manufacturing" is available here: [Survey report, April 2021 (in German)]

How can this tension be resolved?

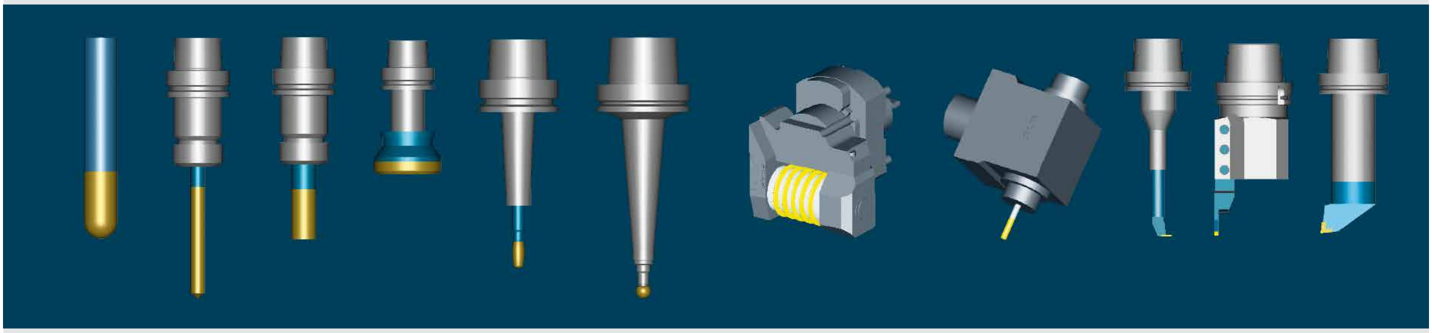
The other face of digitalization

Digitalization doesn't just increase complexity. It also has another face. It helps reduce complexity and make it understandable. Even though the term digital twin may be new, it is not an Industry 4.0 phenomenon (see "A brief history of the digital twin"). If you are already using CAD/CAM software for NC programming, then you have already collected valuable data on which you can build, such as for simulation.

A brief history of the digital twin[4]

The concept of the digital twin has been used in manufacturing since the mid-1980s. At that time, toolpaths were first programmed on the PC, as computer-aided NC programming would be unthinkable without virtual images of the actual production environment. The 3D CAD model, a simple milling cutter and a postprocessor served as the counterparts to the real part, tool, and control in the virtual world of that time. Over the years, more and more modules have been added and would be represented in greater and greater detail: complete tools for milling, drilling, and turning; 3D machine heads and machine models followed, along with units and clamping devices. Today, the virtual and real manufacturing environments are nearly completely congruent. Process sequences and setup situations, including zero-point clamping systems, can also be represented virtually.

Example machining tool
From the simple milling cutting edge to component-based milling and drilling tools to component-based 3D turning tools



[4] A digital twin is a digital replica of a living or non-living physical entity or process in the digital world. It does not matter whether the corresponding entity already exists in the real world or will not exist until sometime in the future. Digital twins enable cross-platform data transfer. They are more than just data and comprise models of the represented object or process and can also include simulations, algorithms, and services that describe, influence, or provide services for the properties or behavior of the represented object or process. (Wikipedia) **https://en.wikipedia.org/wiki/Digital_twin**

The power of small steps

Several examples below show causes of complexity in the current manufacturing world and potential stumbling blocks. Practical tips and advice are provided on how to confidently achieve key digitalization milestones step by step with manageable effort. A quick return on investment shows the success of these efforts and this simultaneously lays the foundation for other change processes that you can implement sequentially, tailored to your company's specific requirements. Digitalization is not a revolutionary change, but rather an evolutionary development.

Minimum CAD/CAM system requirements

The essential prerequisite for a successful digitization strategy is a modern CAD/CAM system.

What a CAD/CAM system has to provide

- Trouble-free handling of complex parts.
- Powerful interfaces with all common CAD systems, external technology databases such as tool databases and measuring systems.
- Design and preparation functions suitable for manufacturing.
- Consistent integration of all CAM manufacturing technologies relevant for production machining, such as 2.5 D machining, 3-axis and 5-axis simultaneous machining or turning.
- Efficient template technology with stored manufacturing knowledge for automated NC programming.
- Use of digital twins for reliable simulation and collision checking.
- Integration with MES (manufacturing execution system) solutions.
- The CAD/CAM vendor should offer support and be able to actively assist you in structuring measures and change processes.

What makes a workpiece complex

- A large number of variants in single-part and small-series manufacturing.
- The need to strictly adhere to geometry and position tolerances as well as center tolerances.
- A potentially large data volume, due to, for example, part size or complexity. Clamping devices and units that have to be transferred to NC programming increase the amount of data even more.
- Multiple manufacturing methods and approaches that need to be combined, such as prismatic machining, 3D machining and turning, along with intermediate steps such as hardening or unavoidable machine changes.
- Geometric properties such as undercut areas.
- Materials that differ in hardness, formability, temperature resistance or rust resistance can be difficult to machine. "Light construction" is becoming increasingly important in the context of climate protection.

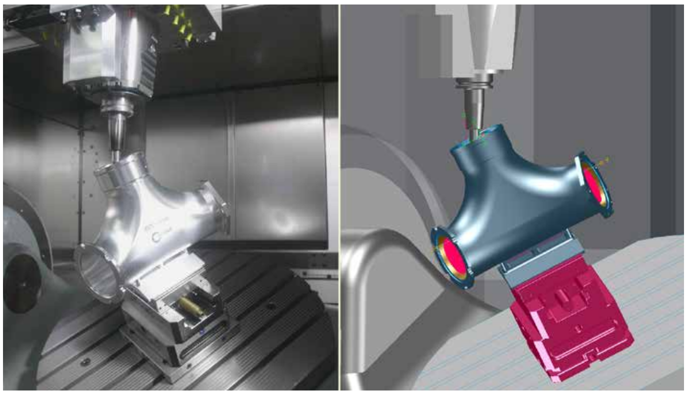
Supporting measures are just as important. Without a process-oriented implementation, the potential added value of digitalized processes is lost.

3

Pathway to the digital world: Milestones, objectives and benefits

For all manufacturing companies, the first two milestones on the pathway to digitalization are digitalizing the manufacturing environment and knowledge. A third milestone is digitalization of the manufacturing processes. It is important to start the digitalization process with a clear plan of action to avoid errors that cannot be easily fixed later. Basic objectives, results and benefits that are key in the digitalization of manufacturing knowledge, environment and operations are listed below.

Milestone 1: Digitalizing the manufacturing environment



Objectives

All components of the real manufacturing world are fully represented as digital twins in virtual databases:

- All 3D tool components with features such as length, diameter, and type, as well as technology data, including precise cutting data.
- Every machine with all components and kinematics.
- Units and clamping devices.
- Postprocessors that ensure that the machining centers act like their digital twins on a 1:1 basis.

Results and benefits

- Easier calculation of machine run times.
- Better utilization of machine potential.
- Improved safety due to better simulation and collision checking.
- Precise part transfer on reclamping.
- New machine tools can be integrated faster on the factory floor.
- Easier planning.
- Less personnel needed for operations.
- Simplified NC programming.
- An established basis for digitalizing manufacturing knowledge, thus for standardized and automated NC programming.

Milestone 2: Digitalizing manufacturing knowledge

Objectives

The company's complete manufacturing knowledge is stored in virtual databases and is available at any time:

- Geometry templates for design and manufacturing preparation.
- Standardized NC sequences.
- NC templates for the same and similar manufacturing tasks.
- Templates for NC documentation.

Results and benefits

- A shortage of qualified personnel can be managed with automated NC programming.
- Faster training of new employees.
- User-related errors during NC programming are avoided.
- Uniform quality of manufacturing results is ensured.
- Access to more industries because a larger part variety is supported.
- Optimized machine utilization through calculated planning and workloads.
- Flexible response to fluctuating order quantities.
- Manufacturing task and machine are coupled.
- Quicker, easier reaction to new customer and market requirements.
- No NC programming on the machine.
- Basis for planning and control with MES is established.

Milestone 3: Digitalizing manufacturing processes

Task and objective

- Increasing horizontal networking.
- All business, technical, logistical, and organizational process stations are digitally represented and networked together.
  - Internal company deadlines as well as deadlines for suppliers and service providers.
  - Setup lists, bills of materials, and materials lists.
  - Manufacturing times and machine utilization.
  - Availability of resources.
- Targeted planning, implementation, and control of all processes.
- Automation of manufacturing such as automatic setup on the machine.
- Targeted specialization and task assignment.
- Digital procurement and supplier management.
- Networking with CAM workstations.
- Precise representation of individual customer processes.
- Continuous variance comparison for ongoing process improvement.

Results and benefits

- Optimal utilization of the machine pool.
- Longer tool service life, because it is known when specific tools need to be changed.
- Transparency and flexibility in manufacturing.
- Budgets are met and on-time deliveries are ensured.
- High degree of personal specialization is possible.
- Basis for further digitalization measures is established.

4 How realization works: Roadblocks and tips

Digitalizing the manufacturing environment

The tool magazines on the factory floor usually include a wide range of tools for all relevant machining types and applications. Versatile machines of different generations are also represented in the machine centers, from simple to highly complex. The devil is in the details when it comes to digitalizing resources.

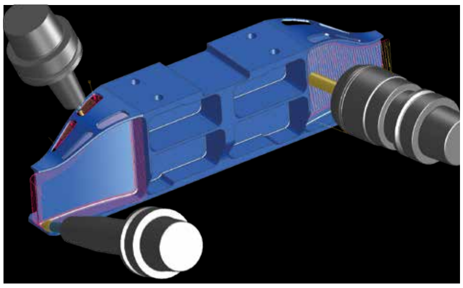
1) Digitalizing tools

Selecting the tool that is best suited for the particular machining operation, as well as the cutting material and data, is dependent on the material to be machined, the tool geometry, and the required surface quality. For example, roughing requires a high material removal rate and maximum tool service life at the same time. In finishing, the emphasis is on surface quality and dimensional accuracy.
In milling, solid carbide high-performance (HPC) tools can cut a large quantity of material in a very short time for parts with deep cavities. Positive results can also be achieved with this type of tool on conventional 3-axis machines. Most companies still use conventional tools such as flat, toroidal, and ball cutters for finishing. Ball insert cutters, and indexable insert cutters or solid carbide quadrant cutters are also used. In contrast, modern high-performance tools such as circle-segment cutters and the special form of the ball-end cutter called “lollipop” cutters are both used comparatively rarely. When needed, however, these tools can save time in both 3-axis and multisided machining, especially when finishing complex parts.

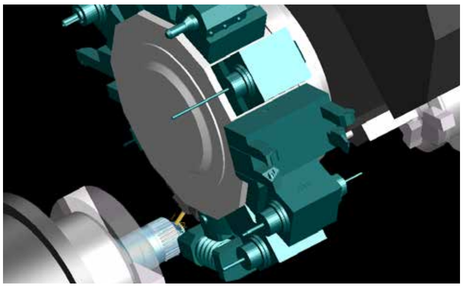
Of course, no production machining company is complete without nonrotationally symmetric turning tools. Special tools for broaching and hobbing are also used in individual cases, as are actuating tools for turning on milling machines.

Tips

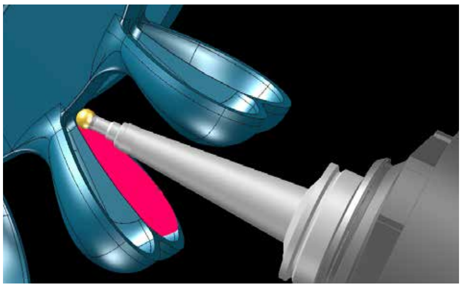
- Check the following before you digitalize your completely loaded tool magazines:
  - Which tools are your powerhouses?
  - Which ones can you do without?
  - Which special tools can be replaced with standard tools?
  - Transfer only the tools you will actually need and use in the virtual world.
- Ensure that the tools can be stored with all cutting data in the database. This is a key prerequisite for automated NC programming accounting for the machine, material, and type of application.



HPC roughing and finishing with circle-segment cutters of a structural part.



Machining with a turret with multiple tools.



Efficient machining of undercut areas with a lollipop cutter.

2) Digitalizing the factory floor

Virtual machines involve a kinematics model representing the accurate geometry of as many machine components as possible, including their dynamic capabilities.

Digitalizing the factory floor has two main objectives: Optimal utilization of all machines and manufacturing safety.

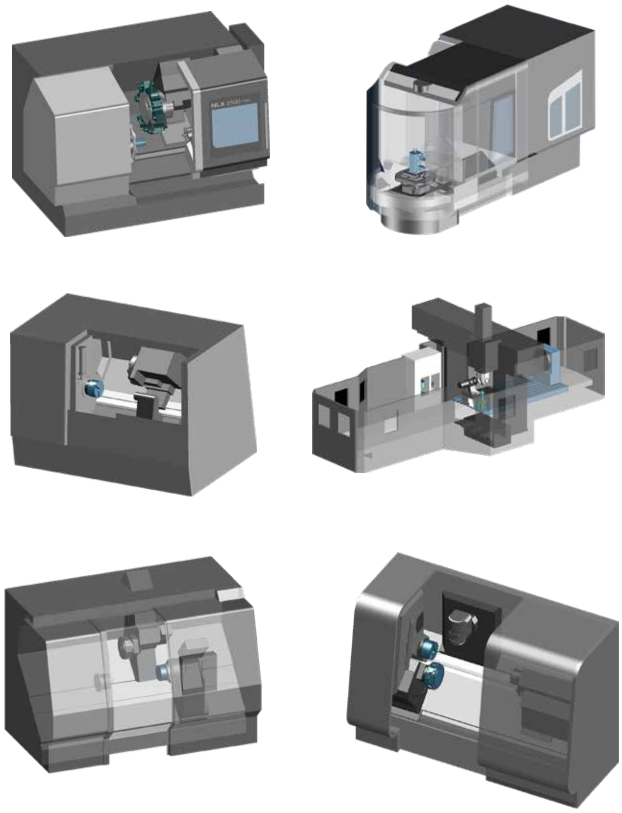
Machine utilization

The overall trend is toward universal machines. This especially includes turn-milling centers with up to four channels, on which the workpiece can be turned using multiple spindles and with 5-axis simultaneous machining. The advantages are that the part can often be completely machined in a single setup. Universal machining centers can also be used flexibly and are therefore suitable for a wide range of parts.

This does not mean that conventional machines, such as ordinary lathes with a main spindle or main and secondary spindles, 3-axis machines, or multi-axis machines with adjustable axes should be removed from the factory floor. An exact cost-benefit analysis must always be performed in advance. Depending on the specific machine utilization and the parts currently being manufactured, it may be advisable to perform roughing or machining of standard geometry (such as pockets, bores, cylinders, or grooves) on a 3-axis machine and then finish free-form surfaces or undercut areas on a simultaneous multi-axis machine, even if the part has to be reclamped.

Safety

For safety, the focus is on reliable collision detection of the virtual toolpaths. This requires that the entire machining scenario be completely verified with all positions and traversing movements already in planning and programming.



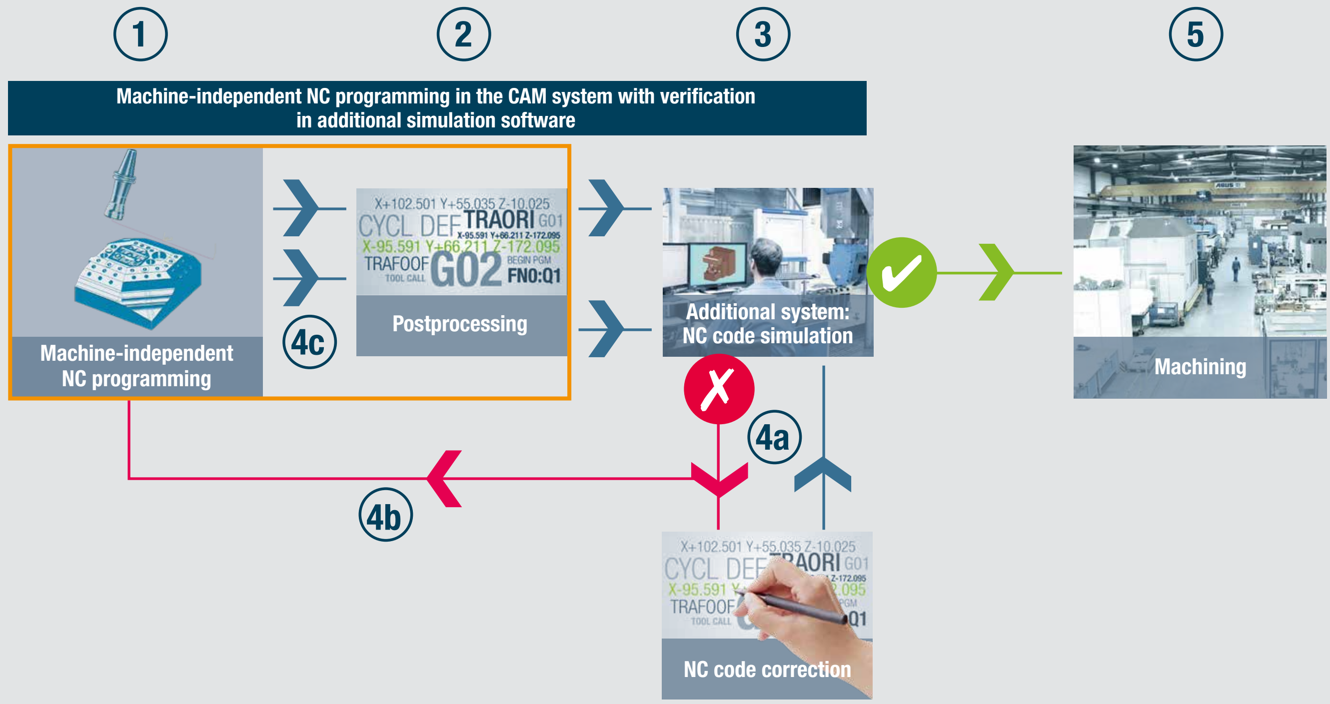
The digitalized manufacturing environment is either used by the CAM system or by verification software. When digitalizing manufacturing, this basic difference between NC programming and verification must be considered in the precision of the digital twin.

NC programming and collision checking. Comparison of methods

There are essentially two different competing methods that are offered by CAD/CAM and simulation software providers.

- Method 1: **Machine-independent** NC programming in the CAM system and verification of the NC code with additional simulation software.
- Method 2: The fully integrated solution with **machine-dependent** NC programming based on precise digital twins of the real manufacturing environment and verification of the toolpaths in the CAD/CAM system.

Method 1

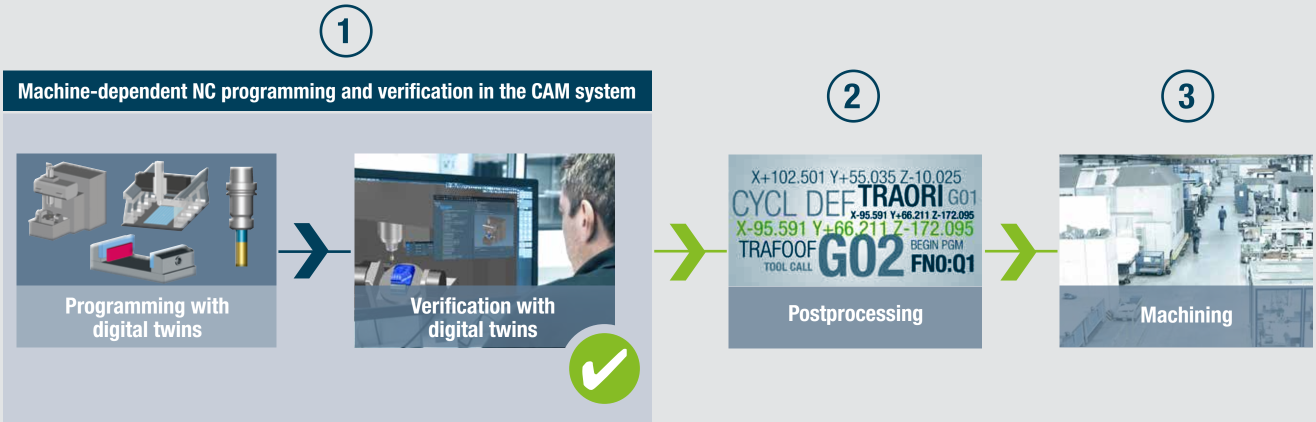


1. In this approach, the NC program is first generated in the CAM environment—**independently** from machine, tool and clamping device models (digital twins).
2. The data is then supplemented with the machine, tool and clamping device information—either before or after NC output depending on the system.
3. The CAM programmer, the production manager or the machine operator then use a separate simulation application to verify the NC code.

There are two possibilities in the event of collisions or other problems:

- (4a) The NC code is manually corrected and then simulated again. If the NC program is generated again later, such as due to changes in parts, it must be corrected and simulated again.
- (4b) If major corrections are necessary, the error must be corrected in the CAM environment.
- (4c) This NC program must be verified again with the simulation software in order to ensure that the correction was successful.
- (5) If no further collisions are detected, the NC program is transferred to production and processed.

Method 2



In this approach, planning, programming and verification take place in the CAM environment using digital twins of the real production environment.

1. From the start, the programmer accounts for all manufacturing-related data for the machine on which actual machining takes place.
2. The programs that are output are completely collision checked.
3. The NC code is sent to manufacturing for processing the part. Multiple correction iterations are not necessary.

Comparison of the methods shows that the second approach, CAM-integrated simulation and collision checking, has many advantages:

- The required number of correction iterations is reduced.
- Planning with machines and tools is improved.
- It is easier, because the CAM programmer does not need to have any special knowledge of machine code or additional simulation software.
- No manual corrections to the NC code that could place process safety at risk are necessary.
- All corrections automatically flow back into the CAM environment, so errors are never repeated.
- The digital twins are managed only once—in the CAM environment —instead of both the CAM environment and simulation software.

Please note:
Simulation of the toolpaths in the CAM system is essentially just as reliable as simulation of the NC code. However, it requires that machine models be completely represented in the virtual world with all their components and kinematics.
Example for lathe: Because the tools are frequently clamped in a turret, changing tools entails high potential risk. Furthermore, lathes use additional machine units, such as steady rests and tailstocks, with which collisions can occur during machining.

Tip
Ensure that your CAD/CAM vendor offers special acceptance procedures for virtual machines and postprocessors. Your machines will be individually measured on site with all additional units for this purpose. A test part will be fully machined with all relevant variants of your NC programs.

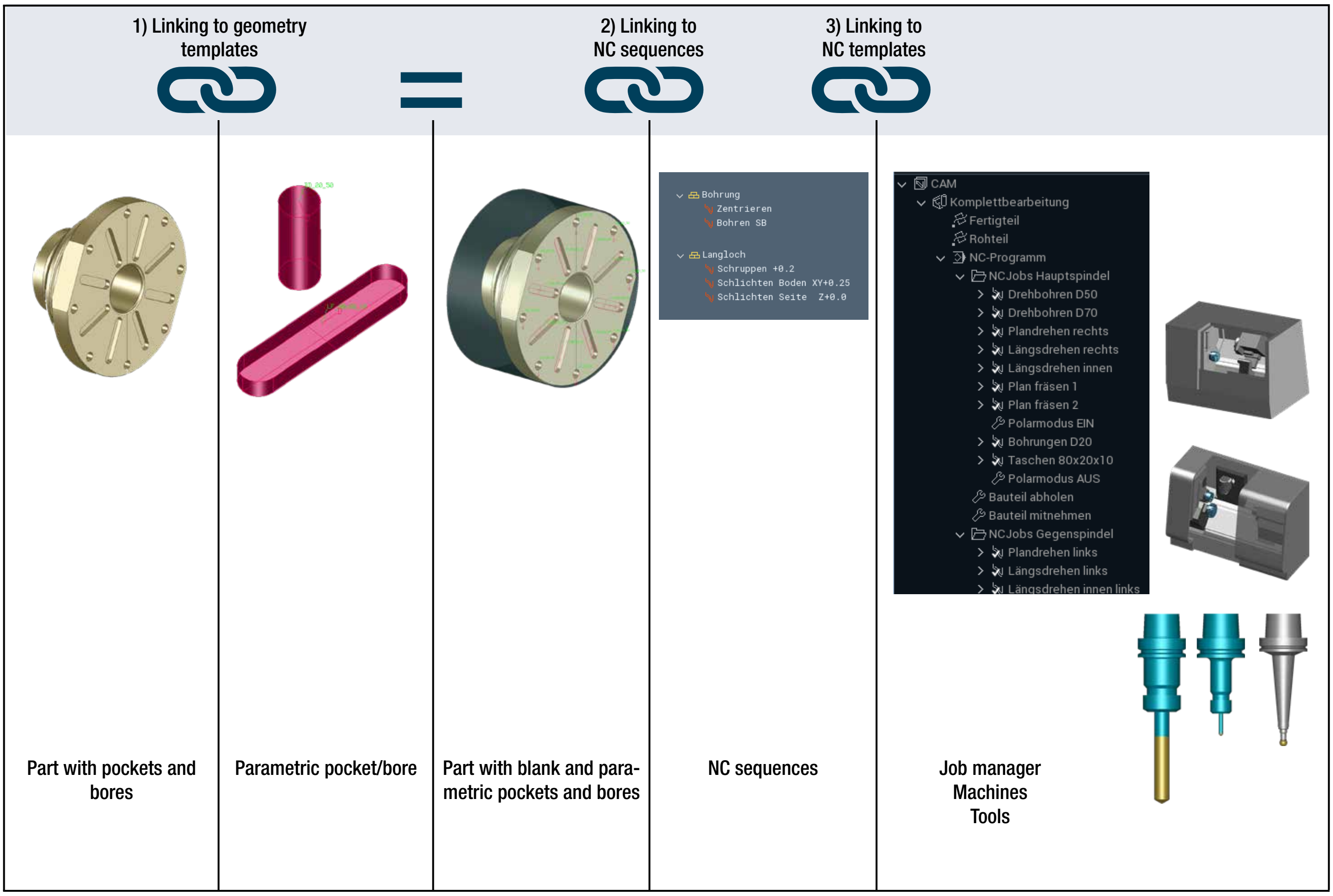
- Due to special certification requirements, it may be necessary to also verify machining using additional simulation software. Your CAD/CAM software should have the requisite interfaces.

Digitalizing manufacturing knowledge

A key hurdle can be overcome with the targeted and complete digitalization of the real manufacturing environment. Many companies make the mistake of stopping halfway. However, the time for general experts has clearly passed in modern manufacturing companies. The responsibility is carried by multiple shoulders. This is due not only to turnover or the lack of qualified personnel: In today’s highly complex manufacturing world, it can be difficult even for experienced employees to determine on a case-by-case basis how to manufacture a part most safely and efficiently, on which machine and at what time. Specialization is necessary, and it should be easy to automate individual work steps. Ideally, departments should be able to coordinate all activities.
The digitalization of manufacturing knowledge is one of the most important steps in this change process. The CAD/CAM software must also provide specific answers to the “how” of manufacturing.

The principle of automated CAM programming

NC programming can be automated to the greatest possible extent with suitable CAD/CAM software based on templates, as can be seen from this example of a simple drilling and pocket machining operation..



1. Linking CAD geometry to geometry templates

A designed CAD geometry does not “know” how it is to be manufactured. Modern CAD/CAM solutions offer the ability to create CAD geometry using manufacturing information or by “scanning” CAD geometry. In this process, the CAD geometry is compared with existing database elements that already contain the necessary manufacturing information. The design geometry automatically becomes a machining geometry.

2. Linking machining geometry to NC sequences

The generated machining geometry is automatically linked to standardized NC sequences, that is, to machining sequences. The machining strategies are stored in the NC sequences together with the appropriate tools, including cutting data, for the machines in your digitalized manufacturing environment.

Notice

You gain a significant advantage if geometry, materials, tools and machines can be described variably and combined into groups as necessary. This adds a high degree of flexibility, because the entire NC sequence is automatically adapted to the specific machining situation and task, based on if-then conditions. Similarly to artificial intelligence, the system learns about more and more variants and can then assign them to the manufacturing strategy based on external features.

3. Linking NC sequences to NC templates

The NC sequences are linked to templates in which the complete machining operation is stored for the same or similar manufacturing tasks. Specific part and material properties, as well as necessary quality requirements, are accounted for. Manufacturing machines and tools are automatically assigned—ideally, with the tools that are already available in the machine's magazine. In a best case scenario, the user only needs to select the machining elements and the blank.

Please note:

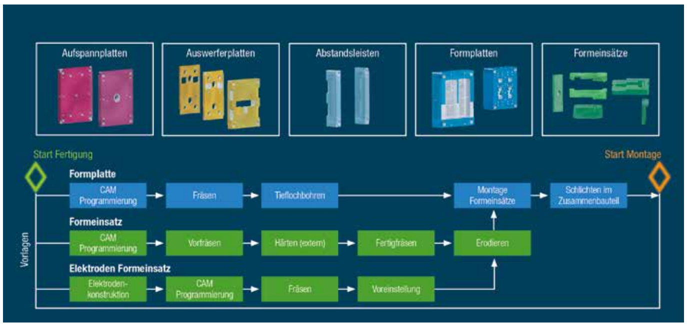
Under no circumstances are templates universally applicable so that they could be used by every manufacturing company. Similarly, proven programming methods should never be replaced with “average” standards. The templates should contain your company’s individual manufacturing knowledge—your corporate intelligence that you have established over the years and that ensures your competitive edge—in a bundled and structured form. If the situation requires, innovative teams of NC programmers and manufacturing specialists intervene in a targeted and flexible manner. They can ensure their experience is built into in the overall process.

Tips

- Use the CAD/CAM software consistently, and transfer as many work steps as possible to the virtual world. Always avoid editing and programming activities on the machine.
- Classify your parts based on useful criteria such as geometry, machining sequence, or complexity.

The next step: Digitalizing manufacturing processes

As mentioned, the concept of the digital twin is a longstanding one in the manufacturing world; however, the idea of establishing digital twins for processes and procedures is relatively new. The next step toward digitalization and horizontal networking lies in the introduction of a Manufacturing Execution System (MES). The goal here is to automate not only CAD/CAM activities but the entire manufacturing process. With MES software, you can plan, manage, and control your process flows with absolute precision—not only the "how" of manufacturing but also the "when" can be determined. The entire process is represented digitally in MES software and is therefore completely controllable. Results from past projects are also accounted for. Another significant advantage is that activities can be specifically assigned. Each employee has access to all the information needed for their specific task at their process station. (see inset)



Complexity of process sequences: Targeted task assignment using MES

Project manager:

- Always has a clear picture of the current status of projects.
- Uses preliminary planning in the proposal phase to check if sufficient capacity is available to meet the delivery deadline.
- Compares target and actual times such as machining and setup times.

Planner:

- Quickly creates job managers for all parts to be produced.
- Automatically generates an optimized sequence of all tasks for all employees and machines.
- Reserves machines and organizes machine changes.
- Quickly and easily integrates repairs and updates the sequences.

Foreman:

- Has an overview of planned and current manufacturing orders.
- Can always see where blanks and parts are and whether they are ready for assembly.
- Can always manually adjust the sequence of operations.

NC programmer:

- Has a prioritized list of programming tasks.
- Has direct access to the design data.
- Can block programs that are no longer up to date in the event of design changes.

Machine operator:

- Has a prioritized list of manufacturing tasks.
- Has direct access to the NC programs.
- Can quickly and easily schedule clamping and manufacturing times.

Tips

- Ensure that the MES software is precisely tailored to manufacturing-specific requirements.
- Ensure that the MES software, as an integration platform, can be easily combined with upstream and downstream systems —such as PDM or ERP CAD/CAM systems or machine control systems.

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Summary, conclusions and outlook

There is no doubt that the production machining industry is faced with many challenges. Digitalization of the manufacturing environment, manufacturing knowledge, and (potentially) manufacturing processes is by no means the end of the line. Sooner or later, every competitive company will have to address current trends such as sensors, automation with robotics, artificial intelligence, augmented and virtual reality and, especially new business models and flexible horizontal value creation systems.

But you can now gain significant benefits from digitalizing the manufacturing environment and production knowledge, for several reasons:

- You remain competitive. You ensure shorter throughput times and greatly multiply your efficiency. Your infrastructure is aligned, so you can quickly adapt your product portfolio to new requirements and expand it as necessary to include ranges from alternative industries. In the Tebis Consulting survey mentioned earlier, 34% of those surveyed indicated a need to reduce their dependence on individual industries.
- The digitalization of the manufacturing environment and knowledge is an essential prerequisite for all digitalization measures in the manufacturing world. With it, you lay the foundation for further change processes over the medium and longer terms.
- With a careful, step-by-step, targeted approach, you can quickly benefit from digital solutions using your existing resources—without overwhelming yourself or your employees.

There are many reasons to remain optimistic. For example, the concept of sustainability that has recently caused so much uncertainty in the industry also carries enormous potential. We can anticipate that there will be clear policy guidelines in this regard in the near future. The revision of the Closed Substance Cycle and Waste Management Act by the German government and the "Green Deal" of the European Union already represent steps in this direction.[5]
This is by no means something to be regarded negatively: Climate-friendly technologies, the mobility turnaround and even the lack of resources offer many opportunities to innovative companies.[6] For example, consider heat pumps and wind generators, the demand for process increasingly lighter materials, recycling of tool components or the development of re-use concepts for tools.[5]
Post-pandemic, VDMA expects production in the German machinery and plant engineering sector to increase by 10% in 2021 and a further 5% in 2022.[7]

[5] Tooling in Germany, 2020, Machine tool laboratory of RWTH Aachen University, Germany, Fraunhofer Institute for Production Technology (in German)

[6] Climate Protection through Digital Technology – Opportunities and Risks, 2020, Bitkom e.V. (in German)

[7] Mechanical engineering industry expects production to grow by 5 percent in 2022, 9/16/2021

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Would you like to learn more about what the Tebis CAM system offers and which well-known suppliers in the industry already rely on it? Then please contact me for a non-binding consultation meeting. My name is Andrea Baron, and I'm a member of the Tebis Sales Development team. I look forward to hearing from you.
andrea.baron@tebis.com • Tel.: +49 89 81803 1429

Would you like to learn more about the specific changes you can and should make? Let's investigate together – we are pleased to offer you a free and non-binding process analysis. My name is Tomek Kawala, and I'm a consultant at Tebis Consulting. I look forward to your call/email.
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