TR463351

Get Up To Speed With Automotive Manufacturing

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Learning Objectives

- Explain the technological solutions that can be used to improve the quality of automotive tooling and the parts they produce.
- Define the challenges that drive change in manufacturing facilities, and explain the use of a unified digital model, to manage projects, equipment and production.
- Identify where automation can be utilized in manufacturing processes to improve production consistency.
- Describe generative design, additive and hybrid manufacturing processes, and explain how they can be used to improve component performance and efficiency.

Description

In this class, we'll cover four topics of automotive manufacturing: mold simulation and CAM, factory planning, automated manufacturing, and emerging design and manufacturing technology. We'll begin with the challenges that automotive tooling companies face, and how the use of new technology and increased machine utilization can address the needs of more-complex and accurate tooling. From there we'll move to factory planning and ways in which to address the challenges that drive change in manufacturing facilities; the problems that arise because of change; and the use of a unified digital model to manage this. We'll then look at how manufacturing productivity can be increased using intelligent automation, and how it can improve consistency and component reliability. And we'll finish discussing the use of emerging technology like generative design and additive and hybrid manufacturing, as manufacturers look to improve performance and efficiency of vehicles to meet sustainability and regulatory requirements.

Speaker

Rob is a Sr. Technical Marketing Manager at Autodesk, where he and his team are responsible for helping customers understand how they can achieve their manufacturing goals, using the advanced manufacturing solutions that Autodesk offers.

Rob graduated from the University of Liverpool with a Bachelor's degree in Aerospace Engineering and a Masters in Product Design and Management before embarking on a career with Delcam as an Applications Engineer. Initially starting in the UK department, he trained and supported UK customers, before moving into an international role, where he assisted the global network of subsidiaries and resellers in both pre- and post-sales activities. Following the acquisition of Delcam by Autodesk in 2014, he moved to Technical Marketing, and is now in his 17th year of service.

Introduction

There are many aspects to Automotive Manufacturing, and whilst it would be informative to go through all of them, we simply don't have time!

Instead, we will cover four key topics of automotive manufacturing, where software can have a major influence.

Beginning with mold and die manufacturing we'll look at the challenges automotive tooling companies face, to deliver quality molds, on-time and on-budget, we'll look at how the use of new technology and increased machine utilization, can address the needs of more complex and accurate tooling.

From there we'll move to factory planning looking at how to address the challenges that drive change in manufacturing facilities, and the needs and problems that arise because of change, focusing on the use of a unified digital model, to manage projects, equipment and production.

We'll then look at how manufacturing productivity can be increased through the use of intelligent automation, and how that automation can improve result consistency and ultimately component reliability.

And we will finish on the utilization of emerging technology such as generative design, additive and hybrid manufacturing, as automotive manufacturers look to improve performance and efficiency of vehicles, to meet global sustainability and regulatory requirements.

The Parts

At different stages, I will be referencing 2 different parts, to help illustrate some of the examples.

The first, is a mass-produced, plastic-injection-molded automotive water pump cover, to help illustrate how changes to the technology and processes you use, can help you produce more complex, accurate and profitable tooling.

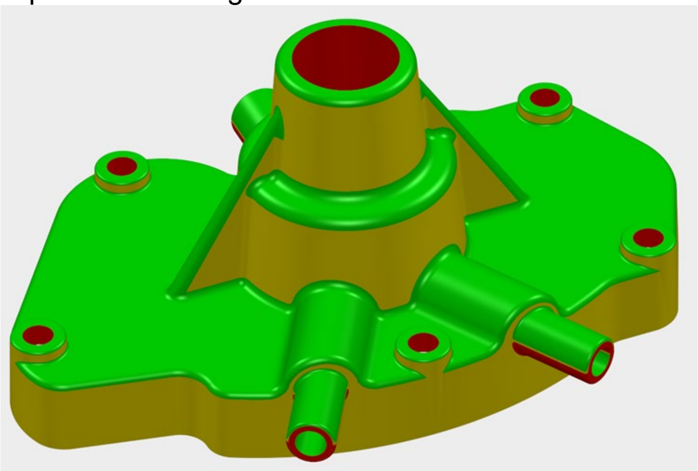


Figure 1 - Plastic Water Pump Cover

The second part is low volume component. A performance car suspension upright, traditionally machined from billet, which will be used to illustrate how emerging technology can increase things such as vehicle performance or efficiency.

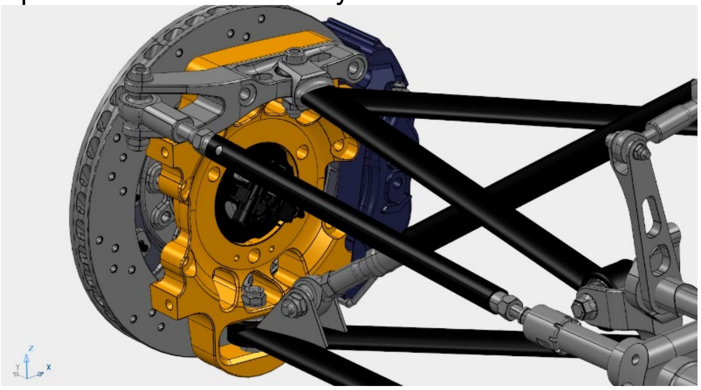


Figure 2 - Performance Car Suspension Upright

Mold and Die Manufacturing

It's no secret that today, the mold and die industry is highly competitive. Manufacturers have experienced international competition which has had an effect on local markets, resulting in a downward pressure on pricing, a squeeze on margins and competition to maintain skilled staff and existing business. They face constant challenges, to deliver quality molds, on-time and on-budget, all whilst trying to achieve margins in that highly competitive market. So in order to regain a competitive advantage, mold and die manufacturers might look to differentiate, with the use of new technology and increased machine utilization, to address the needs of more complex, accurate and profitable tooling. So how are they doing this?

Well, one area where technology can help is in the tooling design itself. When it comes to manufacturing a mold, the most expensive mistake we can make, is creating a mold that produces defective parts. So we look to technology, which can help minimize this risk. One example is Mold Simulation.

Mold Simulation

So what could possibly go wrong with the manufacturing of a molded part? Well, quite a lot, as it happens! Firstly, the plastic can warp, and it invariably shrinks. It can fail to solidify completely, or even solidify too soon, potentially leaving unsightly weld marks on the part. Differential rates of cooling between thicker and thinner regions can result in surface depressions called sink marks, not to mention air traps, short shots, core shifts and more. So how do we prevent these from happening in production?

Traditionally the mold manufacturing process might look something like *Figure 3*.

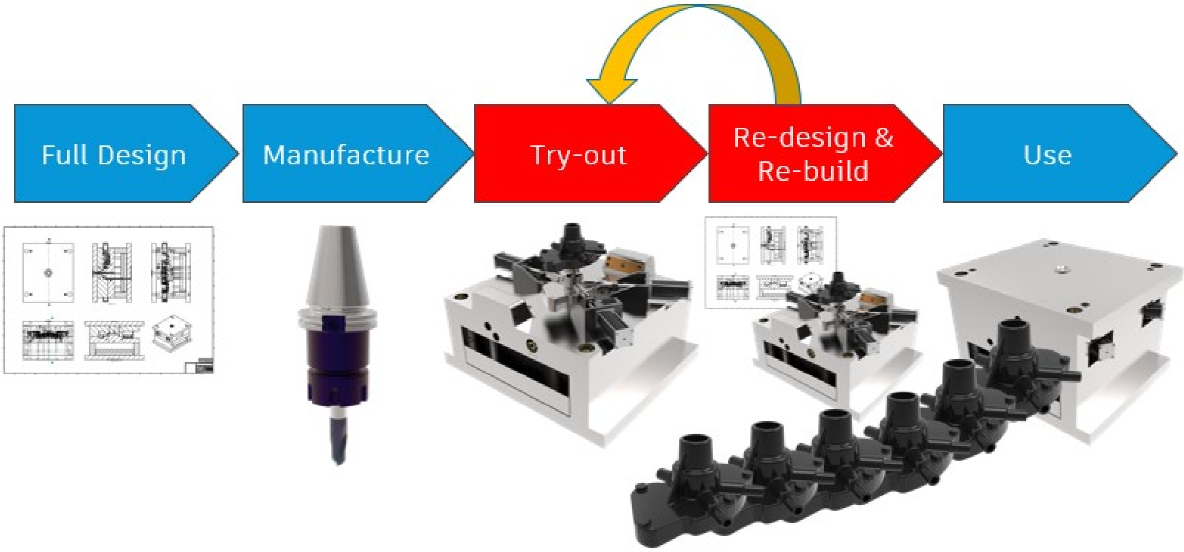


Figure 3 - Traditional Mold Design Workflow

In this traditional process, the part model and drawings are received from the customer, with design options discussed and any metal-safe areas defined. The tool is then designed, based on past experiences. For example, from other parts they've run, past re-designs they've had to do, and so on. The mold can then be machined.

Once completed it can then be tested, either by the tool maker or the manufacturer. This then begins a cyclic process for any adjustments required, based on trials, such as resizing metal-safe areas, adding flow leaders, and so on. Once the final adjustments are made, the reconfigured mold is re-tested, and if approved can then be put into production.

And it is this costly testing and reworking that is a major bottleneck in the process, with little guarantee that the problems mentioned previously will be rectified.

To combat this, we can use mold simulation software. Advanced simulation software lets us review wall thicknesses and gating locations, and find undercuts and draft angles. It also helps identify the part quality, in terms of warpage, cooling and filling ability, and can advise on costs and design options, helping identify geometry changes required early in the design process.

Simulation can provide analyses catered to specific molding processes, such as thermoset and compression molding, along with more advanced options, such as induction heating, inserts, transient cooling and valve gating. Materials databases can be used to test thousands of thermoplastic and thermoset materials, as well as different mold materials, with the options to export results, mesh, and CAD data, for post-processing in FEA, CAM, or visualization software.

All of which help optimize the part and tooling for the required part quality and cycle time, reducing manufacturing defects and getting your products to market faster.

So, what happens to the workflow, if we include simulation in the process?

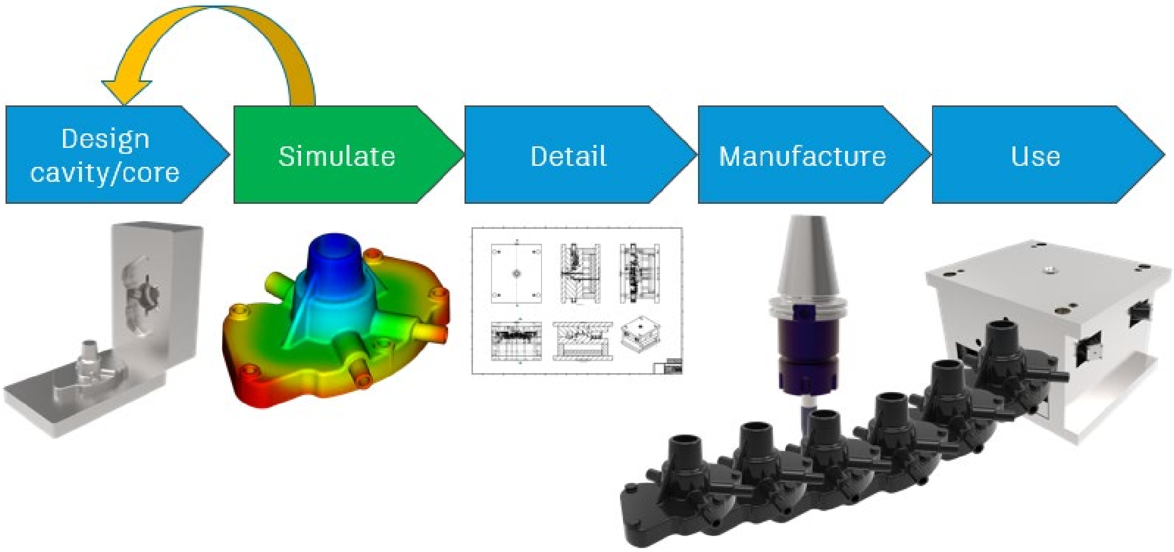


Figure 4 - Mold Design Workflow with Simulation

Looking at *Figure 4*, the part model & drawings are received from the customer as before, but this time just the core and cavity are designed initially. At this point simulation can be introduced, to analyze the initial design assumptions around how the part will be made.

The cyclic development can begin here, early in the process, with analysis and iteration helping you to answer critical design questions before they become expensive. This simultaneously improves part quality by identifying imperfections such as sink marks and weld lines, and reduces cycle times through the experimentation of advanced cooling options (which we will come to later) or heating methods.

Once the final design is achieved, the detailed design can be done, then the mold can then be machined, and put into production.

So, introducing simulation early in the design of the tool, can greatly help reduce the risk of delays and costs, that were originally a result of tooling redesign.

Expert CAM

So, we’ve seen how adding mold simulation into our design process can improve the quality of our final product. But what about the manufacturing of the mold itself? Let’s take a look at how utilizing an Expert CAM solution can help.

When it comes to machining molds, there are many ways to manufacture the cores and cavities. Traditionally the default choice has been to use 3-axis vertical CNC milling machines, and they continue to provide a good solution for many applications. But higher value mold tools, which can yield more profitability for the manufacturer, often come with increased complexity, or higher demands for accuracy.

So automotive mold manufacturers turn to their 5-axis CNC machines (or invest in them if they don't have them), to tackle the more challenging molds, because using 5-axis machines means fewer setups are required, which not only boost productivity because less time is required to set up, but also minimizes the loss of accuracy that can happen when changing the setup.

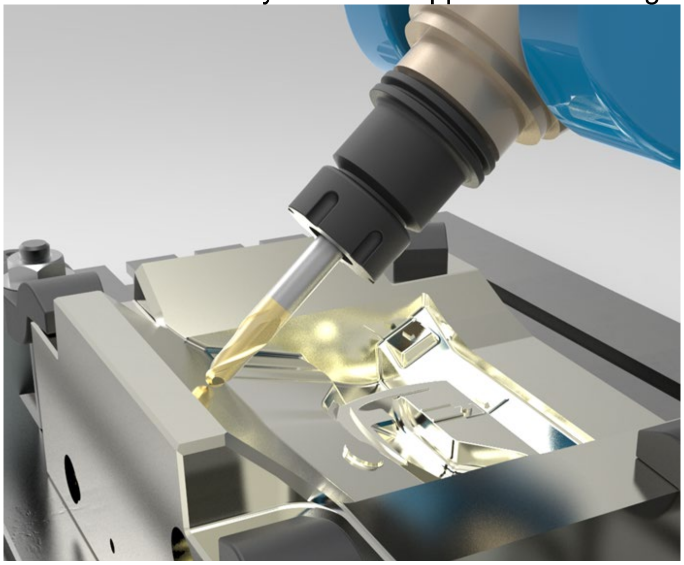


Figure 5 - 5-Axis Mold Machining

Tilting the tool allows better access to deep cavity features and tall core forms. And because the tool can be tilted, shorter tool lengths are required, which means tools are more rigid, and therefore vibrate less, increasing the machining accuracy further. And it is because of these benefits that the need for post-machining processes, such as hand finishing, are minimized.

So, what do you need to look for in your CAM software, in order to achieve maximum productivity and finished accuracy?

Obviously, you need High Speed Machining capabilities, which not only helps your machine run quickly, but efficiently, reducing tool loads. Smaller loads, mean tool wear is minimized, and because your tools are protected, the machine can run at more aggressive, optimized feedrates. Advanced finishing strategies, with parameters to optimise the toolpaths, can eliminate unnecessary hand-finishing and improve repeatability and accuracy.

Control of both the toolpath and the tool is important. The ability to edit toolpaths is needed, to optimise their use, without unnecessary toolpath recalculation. And the capability to dynamically manipulate axes, to achieve optimum tool and machine orientation, is also desirable.

The important thing here is enabling greater control will improve surface finish and tool life, and lead to significant savings in time.

And it shouldn't stop there. When dealing with the complexities of multi-axis machining and expensive mold tools, accurate machine simulation and verification become ever more important.

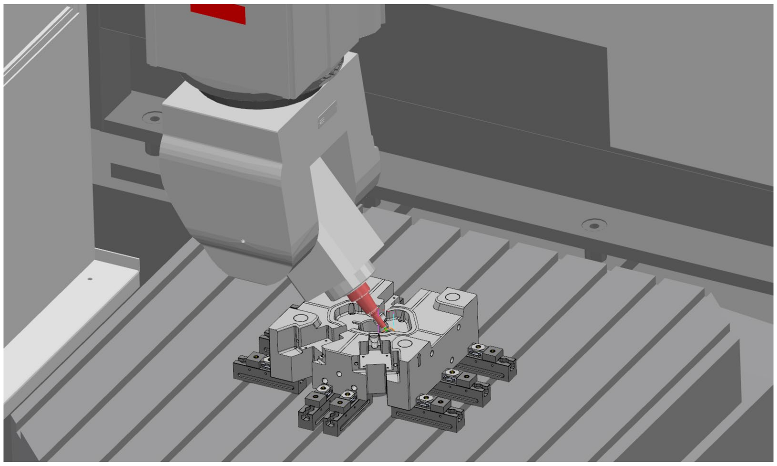


Figure 6 - Machine Simulation in PowerMill

Integrated simulation and verification enables better utilisation of CNC machine tools, creating safe and efficient machining. Simulation and verification enable setups to be optimised before setting up on the machine, eliminating the potential for lost productivity due to setup inaccuracies.

Identifying the optimum workpiece setup for each individual machine tool, allows machine tool capacity to be utilized for production, not wasted through workpiece setup, and collision detection and avoidance minimize the chances of damage to the workpiece, cutting tool, tool holder and machine, that could result with collisions.

This, in-turn, inspires confidence to run toolpaths unattended and over-night, increasing productivity by maximizing existing capacity through un-manned production, and increasing return on investment of your machine tool.

All of these factors save time and money, and ultimately increase the capability for more complex and profitable work.

Factory Planning

So, we have looked at how technology can improve what happens inside our factory. But what about planning the factory itself?

To help us understand where we are coming from, let's look at what is driving change in Automotive factories.

Figure 7 - Reasons for Change, in Manufacturing

Demands on your production facility are constantly changing. Change is inevitable. *Figure 7* shows some of the reasons why automotive manufacturers have to cope with change.

You may have a new product that you are introducing into the market, or your customers may be demanding better performing products, or more efficient products, or they may even be asking for personalization, which requires mass customization of your products.

You may be concerned about the sustainability of your processes, or you might be facing new regulations, or you may be faced with concerns about your budget and are looking for ways to reduce costs, or maybe you're looking for ways to fund new equipment, or perhaps your sources or transportation supply chain are being disrupted.

And we know that these are common problems, because we conducted a survey with Tech-Clarity, a leading research firm in the manufacturing industry. Tech-Clarity surveyed over 250 manufacturers across the globe, so we could better understand how you approach change in your factory, and what the best practices are to manage change? We learned a lot.

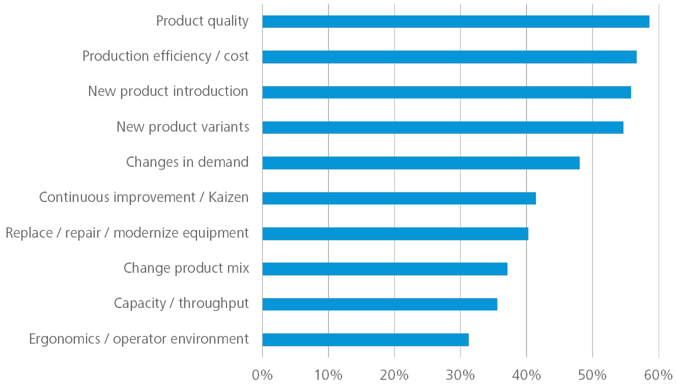


Figure 8 - Top 10 Drivers of Change in the Factory

From the survey we learned that the top three contributors to change are quality, cost, and new products.

It is the ability to adapt quickly in manufacturing to implement these changes in response to market pressures that is critical for long-term business growth. Adaptability helps you launch new production lines quickly, continuously improve production efficiency, reduce costs, increase quality, and ensure a safe working environment so that you can ultimately hit your top-level business objectives.

But what happens if you are not able to manage those changes effectively? To put it simply, it *could* negatively affect your long-term business growth.

If we expand on that, the way you run your factories or your production sites is not a revenue generator like sales.

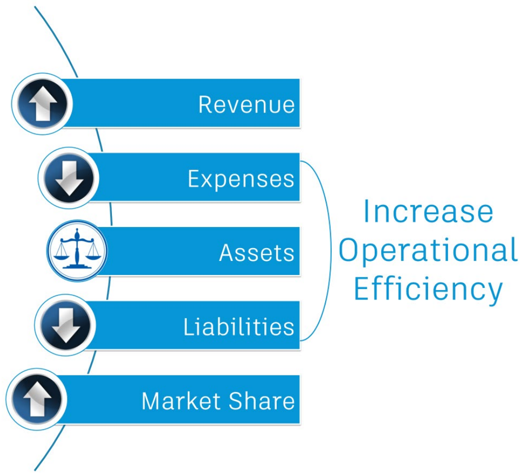


Figure 9 - Increase Operational Efficiency

But if you manage your expenses well, or if you manage your equipment and building assets well, you can mitigate risk and liabilities increasing your operational efficiency, which can have a positive impact on your bottom line.

Our study also identified the most common problems which occurred when implementing manufacturing change projects.

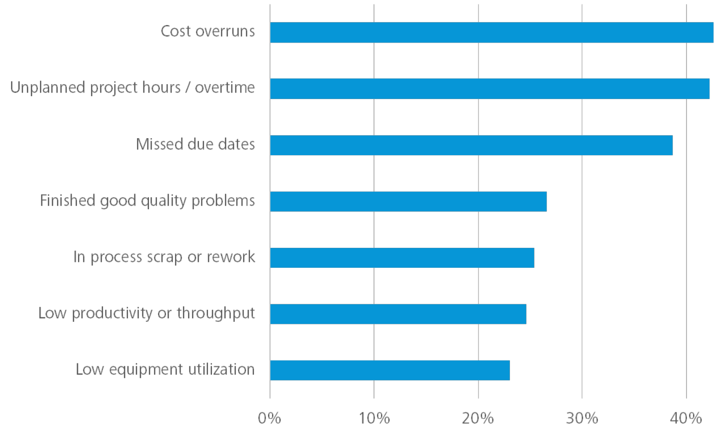


Figure 10 - Common Outcomes of Factory Change

The top three are all project-related and relate to "determining the cost of change", those being cost overruns, unplanned overtime, and missed due dates. The next four have to do with missed production goals that relate to "understanding the impact of change" quality problems, scrap, low productivity, and low equipment utilization. But it's all these challenges together that impact the business objectives that manufacturing is responsible for.

It's difficult to maximize profitability when change projects exceed the budget or schedule, or when the production line does not perform as efficiently as required.

Challenges

Now the challenges that you are faced with, present an opportunity to improve. But there is also risk involved. Not just for managing production, but also those who are in charge of managing the facility or the building. When we work with customers to identify the sources of these issues, they generally fall into three categories as the production line is being developed.

The first is poor collaboration. There are many different people with different responsibilities that need to be involved in change projects. We often hear from customers that they are dealing with ongoing issues simply because they weren't able to see the problem together while the line was being planned.

The next is inefficiencies in the design process. The time of a manufacturing engineer is extremely valuable. If that time is wasted with inefficient tools or processes to create or document the design properly, then they are not able to contribute their maximum potential to the business.

The last cause is the inability to test designs. One of the biggest challenges from the survey was not knowing the result of the change. Testing designs to determine throughput or productivity, or even to test the installation sequence to make sure it's feasible within the schedule – are critical to knowing beforehand.

Figure 11 shows some example costs.

Example: Impact of Cost & Schedule Overruns	
Item	**Description**
Project delay $100,000/day	Opportunity cost of project taking longer than planned
Field check $10,000/incident	Time required to measure factory environment
Field change order $20,000/incident	Fix issues found during build out
Major interference $100,000+ /incident	Collision between machine and environment

Figure 11 - Impact of Cost & Schedule Overruns

Using the automotive industry from our survey as an example, project delays can cost $100,000 per day due to the lost opportunity costs associated with the project taking longer than expected. Missed or incorrect measurements while field checking can cost upwards of $10,000 per incident depending on when they are found. Obviously, the worst time being upon the installation of the equipment. Change orders in the field can cost $20,000 per incident and major interferences between the equipment and the building can cost a lot more that.

And this doesn't even mention the cost of missed production goals. What if a production line coming online runs at 80% efficiency rather than the targeted 90%? At the end of the day, getting the design of production lines done right the first time is critical to protecting and maximizing the profitability of your products.

Plan, Commission and Operate

From the earliest production concepts, to continuous improvement in operation, Autodesk solutions help bring together the entire project team to design, construct, and operate a highly efficient factory.

Let's look at 3 key areas, those being; plan and design, making better decisions during commissioning, and operating your factory efficiently.

Figure 12 - 3 Key Areas of Factory Planning

Plan and Design

When It comes to efficiently planning and designing a facility, it helps if your teams can collaborate on an integrated factory model, which can fully optimize production. Doing this can reduce risk and often lower cost.

So how can we help improve design efficiency, during process, production, and site planning, and how are we going to identify the opportunities to improve overall factory efficiency?

3D virtual walkthroughs can help. 3D virtual walkthroughs (see *Figure 13*) are great for stakeholders who have a hard time understanding what the facility is going to look like as a 2D drawing. This is even better than looking at a 3D model in a typical CAD system because the walkthrough is so easy to use, where there are even saved views, that you can use to return to a previous view.

Figure 13 - A 3D Virtual Walkthrough

This is a great way to coordinate the team when you are holding a review session, and is a really helpful way to gain a good understanding of what the building and installed equipment is going to look like.

So how do you work with the as-built state of your facility, when you don't have CAD data?

Laser scans are a great way to capture the current state of your facility, providing a quick way to get a digital, 3D model of your facility into a format that is easily understood. It provides a high-resolution representation of the space, which is less expensive, less time consuming, and more accurate than manual field checking

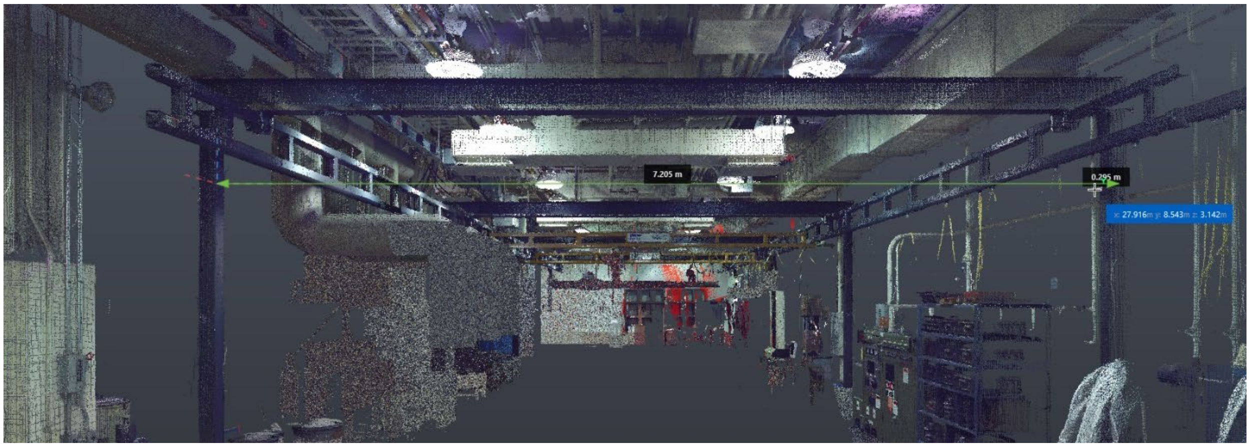


Figure 14 - 3D Scan of a Building in Autodesk Re-cap

Once you have a 3D scan, you can reference it into Inventor or AutoCAD as a design aid, or you can include it in your coordinated Navisworks model for clash detection.

Whilst laser scans are going to help you to accurately capture the current state of your facility, to verify your equipment can be installed without any collisions or interferences with the components within your building, they cannot help analyze and visualize efficiency of your project.

This is where Process Analysis comes in.

Process Analysis is used to model, study, and optimize manufacturing processes. By visualizing the process, you can identify potential bottlenecks or opportunities to improve efficiency, not just before they occur on the factory floor, but even before you begin inserting equipment into your design.

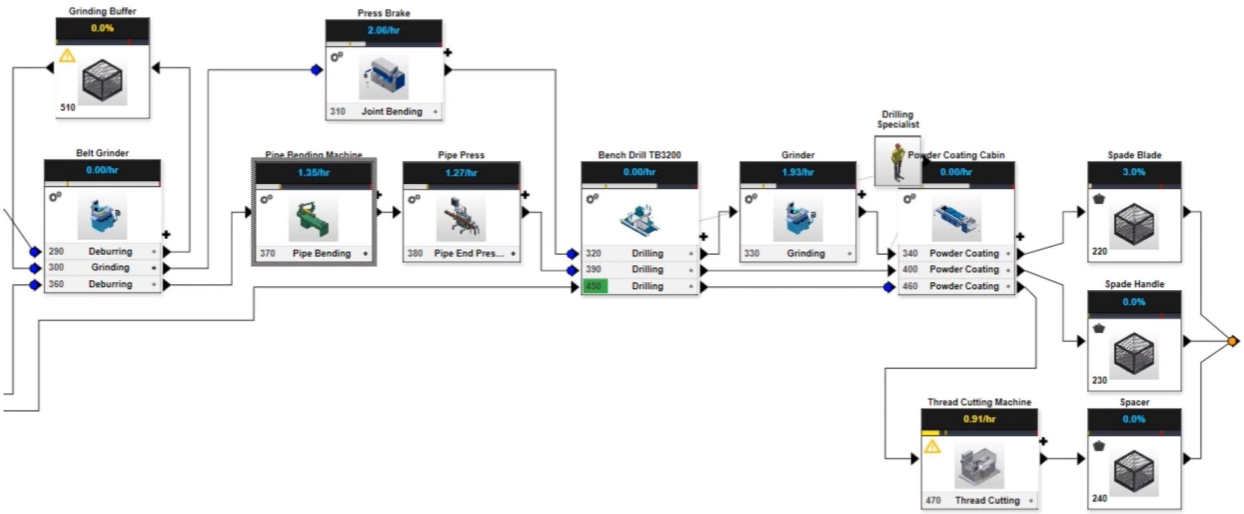


Figure 15 - Process Analysis

Raw material, processes, and buffers can be connected, to form a work cell or assembly line, before you get to the end product, and if you are currently tracking a process model in Excel, then that can be imported into Process Analysis to create a model design, which can then be run.

Specific takt time targets can be entered, and applied in your report for line balancing, and the report can then be used to compare against your set target, with cycle time charts available, to visualize the results of your simulation.

Once a process model design has been created, it can be exported as a DWG file, which can be brought into AutoCAD, with the ability to sync the data with Inventor so you can view it in 3D, repurposing your work, without having to set it up again.

Taking the information learned from the process analysis, this can be mapped into real world coordinates, to produce a digital simulation that can be used to analyze material and facility flow to fully optimize equipment placement.

Designers can layout production lines in 2D while using asset libraries to create 3D factory models, and integrating production lines into your BIM model of the facility.

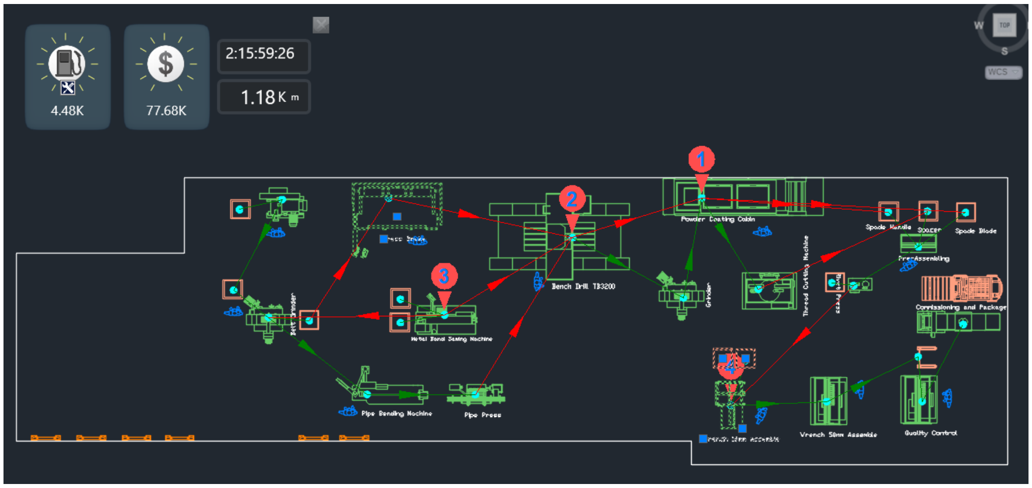


Figure 16 - A 2D Facility Layout in AutoCAD

From this we can analyse our layout for machine utilisation and power consumption as materials flow through the factory to become products, or we can analyse the transportation cost of the product, looking at how much time it takes for materials to travel through the factory and how much distance they have to travel.

Construct and Commission

When it comes to commissioning, communication is a key element in order to stay on schedule, and on budget, especially during factory change projects. We need to look to communicate design decisions across the entire project team using a single digital model, which integrates equipment, production line layouts, building designs, and reality capture data as a single database of project information.

An integrated model of the existing and new facility, and the production systems is required, with the ability to detect clashes and collisions before the project starts. We also need to provide project teams with insights into any potential scheduling issues that could delay production.

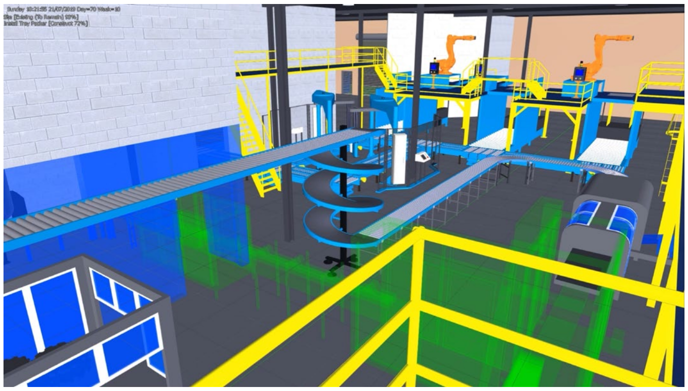


Figure 17 - Data Compiled into One Navisworks File for Coordination

Assets from AutoCAD, Autodesk Inventor and Revit being compiled into one Navisworks file for coordination (see *Figure 17*), which can not only be used to visually check and coordinate designs, but can be used to detect clashes and mark up our design for review as a team.

Data can be added, or imported from Microsoft Project, for the project timeline, and the installation sequence then be animated. The ability to visualise the installation sequence, including temporary works or material staging, is a huge benefit which keeps the team on track.

One problem facing design teams is the ability to collaborate with stakeholders outside the firewall, so it is also important for there to be a seamless exchange of data between the factory equipment and the BIM model.

Coordinated design models can be saved to Autodesk Drive, which automatically syncs the file to BIM360 Docs. Designs in BIM360 docs can then be shared with your wider team, with complete permission control, to understand and review the coordinated model at each stage of your project. Stakeholders don’t need to visit your facility and they don’t need to install any software, they just need the secure link and an internet browser to participate.

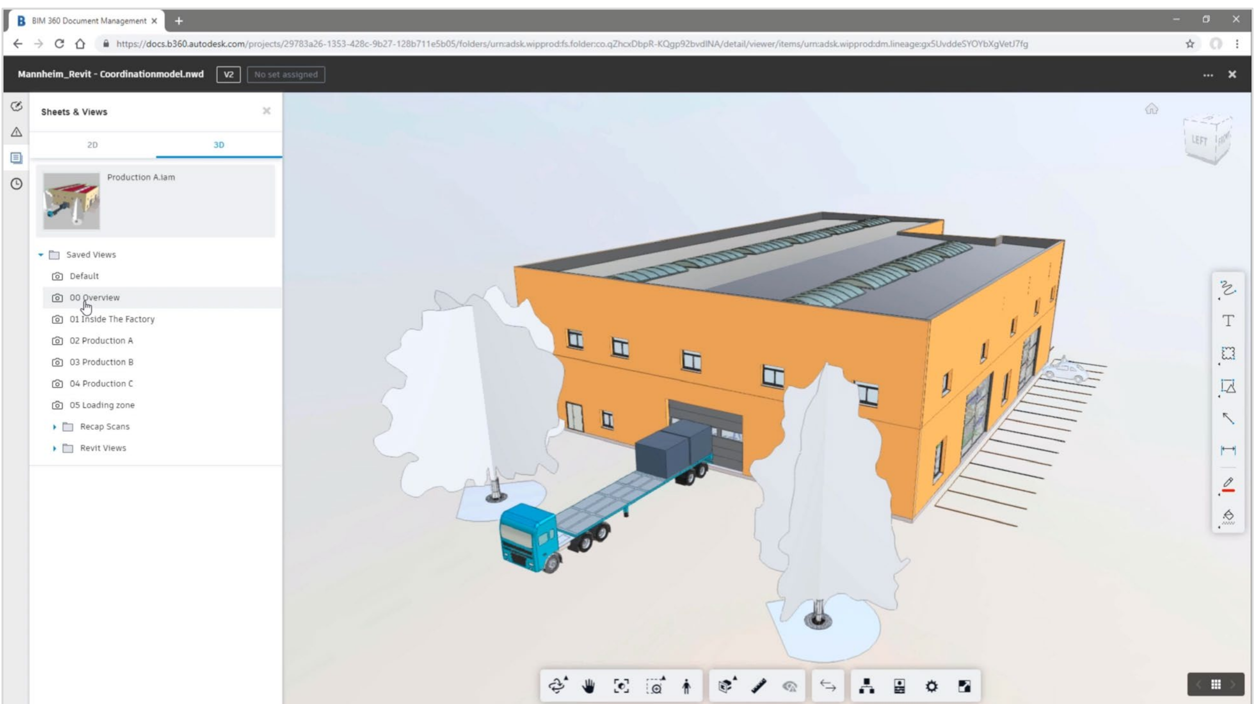


Figure 18 - Shareable Factory Model in BIM360 Docs

Operate

Once up and running, we will want to look at continuous improvements in the way our factory operates, and we can do this through the continued use of our integrated factory model. But none of this works without managing your data properly.

So, you need to ensure that everyone is working from the same data, which is revision controlled, so you know you are working from the latest design. This means there aren't multiple copies of files on each computer, but rather one centralized data management system. Just as before, the production line and building design cannot be done efficiently in silos. You need a system, where they can be integrated. All this results in work instructions that are delivered accurately, and quality procedures which are followed in the production process plan.

Summarizing this section, Autodesk covers all the phases of the factory lifecycle.

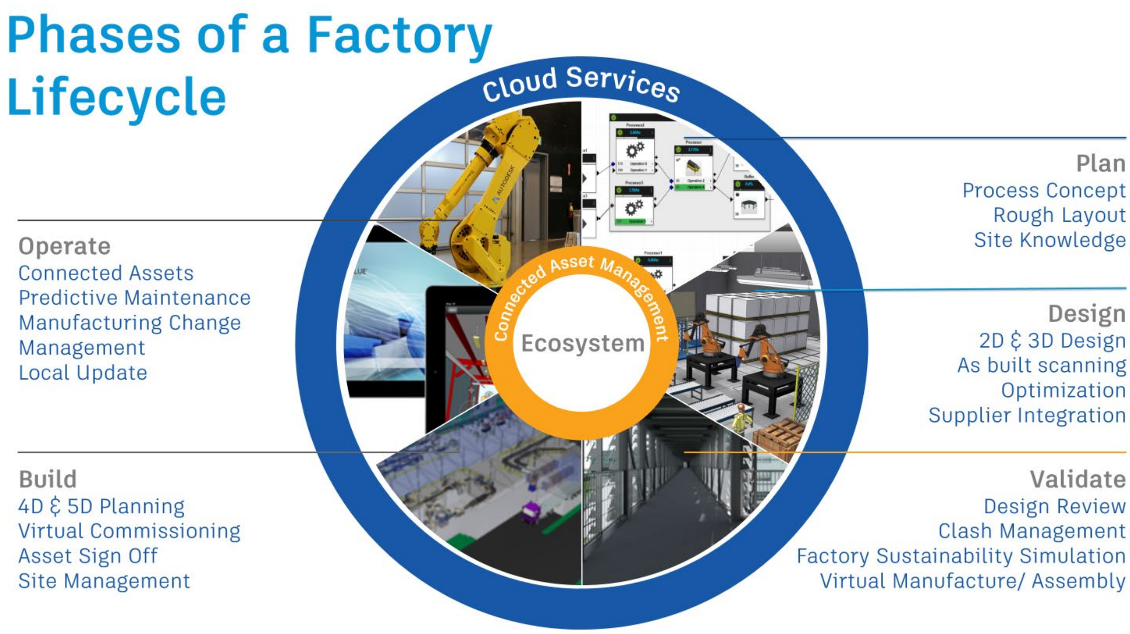


Figure 19 - Phases of a Factory Lifecycle

Starting with your goals, you can validate your design digitally before you even start up CAD, finding out what your throughput is going to be, and where the potential bottlenecks are. That concept can be used in your design, in AutoCAD or Inventor.

In the validate phase, design reviews can be performed, with virtual walkthroughs, aiding interference detection between the equipment and the building. Then it's time to install the equipment, with the installation and commissioning process starting with the planning tools in Navisworks.

And finally to operation, where we look to link master data from the physical equipment back to our factory library in AutoCAD and Inventor. This way we can better plan for the next factory layout. It is a connected, closed loop solution, and supported by cloud services.

Automated Manufacturing

So now we have our factory running smoothly, how can we automate our processes internally to make efficiency gains in our production?

In the world of automotive manufacturing reliability and time to market are critical to success. So automotive manufacturers look to improve processes through the utilization of automation. Automation can deliver repeatable and consistent processes, which improve quality and will ultimately result in more reliable products.

But first we should establish what we mean by "Automated" in the context of this section? Now, automation within the automotive manufacturing industry comes in many forms, from assembly lines themselves, and the industrial robots that assemble and weld on them, through to the automated guided vehicles (or AGV's) that transfer sub-assemblies and components around the manufacturing floor.

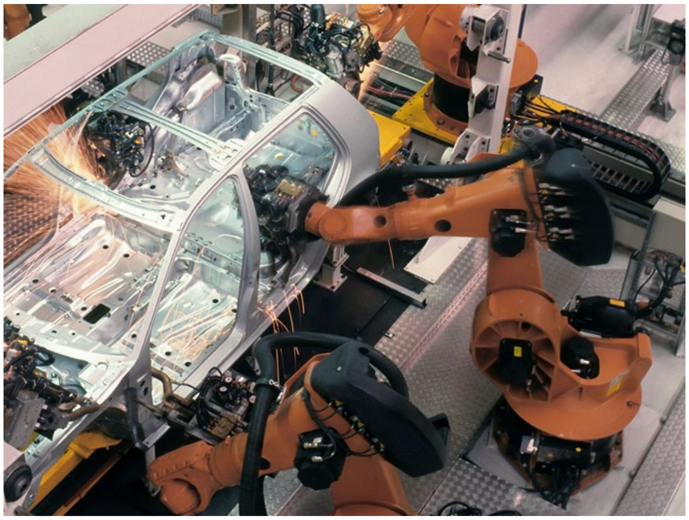


Figure 20 - Robots Spot Welding on an Automotive Assembly Line

But, as exciting as those topics are, sadly we do not have enough time to cover all of them. So, for this section, we will be focussing primarily on software solutions to help automate the processes for design and manufacturing using CNC machining.

Guiding Principles and Challenges

Before we begin to look at software solutions, it helps to look at some guiding principles that we can use, and challenges that we might need to solve, in order to be successful.

In terms of Guiding Principles, I wanted to briefly cover Lean Manufacturing. Originating in Japan, Lean Manufacturing is used as a method to minimize waste, whilst maintaining productivity, by focusing on what adds value during a manufacturing process.

By doing so, Quality Improves whilst Production Time and Cost are Reduced, and these same principles can be used throughout the manufacturing process.

With that understood, what challenges might we face where automation might be able to help? Well, the skills gap is something that has been widely spoken about, but fundamentally comes down to the gap between the number of skilled jobs available and an apparent lack of skilled people to fill those roles.

Part of this problem is down to an aging workforce which, once retired, takes a lot of craft, skills and knowledge with them. This is difficult to pass on in a traditional sense, so capturing this knowledge is vital to maintaining skill levels within an organization.

Therefore, we might look to software that can help capture this knowledge and store it, for use by others within the organization, allowing best practices to be shared and collaboratively refined later.

There is also a fundamental shift happening in manufacturing companies. As manufacturers begin to embrace advanced technologies and automation, this in-turn is having an effect on the skillsets required.

So, to narrow that gap automotive manufacturers will look to software that has a reduced learning curve, allowing users to get trained up in as short a time as possible, reducing the time it takes to become productive.

Intelligent Automation

When it comes to programming parts, traditionally a programmer must make many decisions manually, in order to achieve a desired result that can be sent to the machine. Unfortunately, these decisions can waste valuable time, especially when the decisions that need to be made are repetitive ones which could be easily automated.

Intelligent automation can therefore be used, automating repetitive tasks such as tool selection, feeds and speeds, and stepovers and stepdowns, based on material selection and part dimensions, speeding up part programming dramatically. This allows programmers to spend more time adding value to the process, either by getting the part on the machine as soon as possible, or by using the time saved to perform full machine simulation and collision checking.

Taking this a stage further, intelligent automation can be used to program whole parts entirely.

Automated part programming technologies, such as Automatic Feature Recognition (see *Figure 21),* can identify machinable part features, and then in-turn use the same automated decision tools mentioned before, to fully program a part with little more than a few mouse clicks in a wizard. The results can be fine-tuned if required, to maximize the process efficiency, and because it is automated the results are both consistent and repeatable.

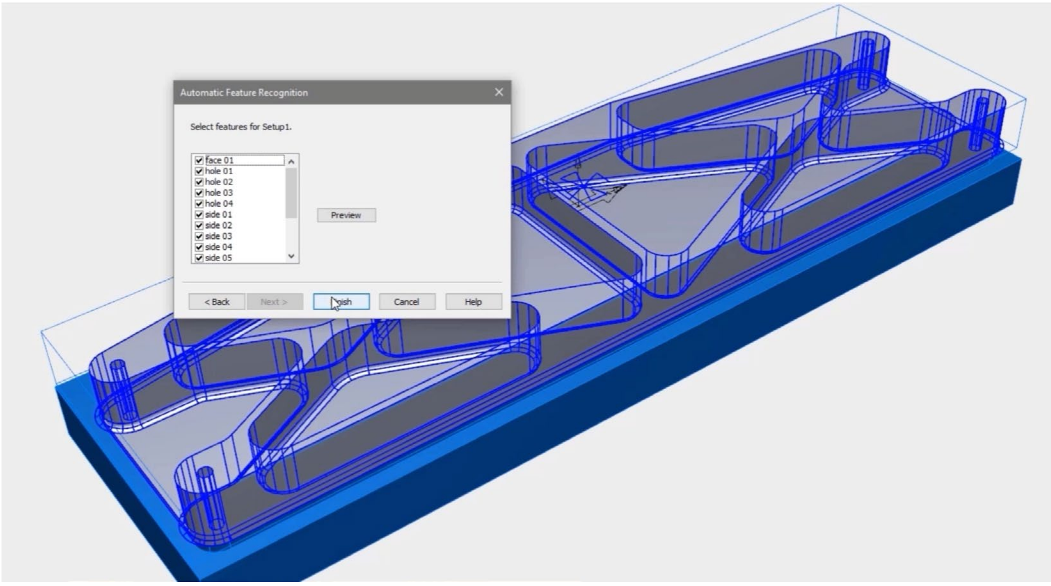


Figure 21 - Intelligent Automation in Action, with Automatic Feature Recognition in FeatureCAM

Customized Automation

Building upon the ideas of intelligent automation, automated decision settings can also be customized. This can be done either by modification of default values which dictate the automated decisions, or by saving the processes as templates, or perhaps macros, to be used later.

By doing this, the knowledge of the most experienced users can be captured as “best practices” and saved for future use, which benefits less experienced users, and improves programming consistency, repeatability and quality, since everyone will get the same automated decisions. And because customizable settings can be saved, they can also be referred to by intelligent automation processes such as feature recognition.

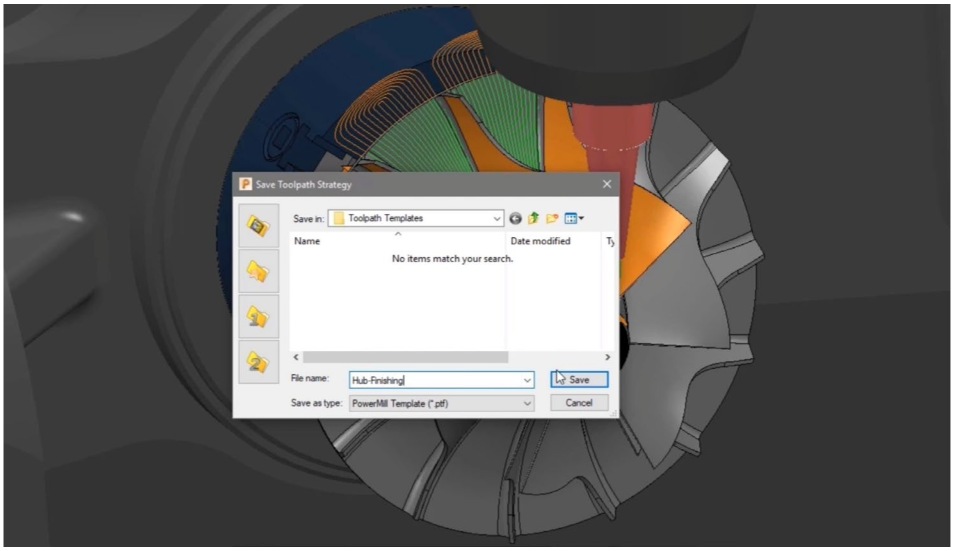


Figure 22 - Complex PowerMill Programming Operations can be Saved as Templates

Automation can also help when it comes to parts that are customized by the consumers.

When it comes to customized parts, or families of parts, automation can be used reprogram parts based on customized requests. For example, common features and processes can be saved into databases and called upon at a later stage, with minimal input required from the programmer, as all programming details can be saved and then quickly recalled for the next part.

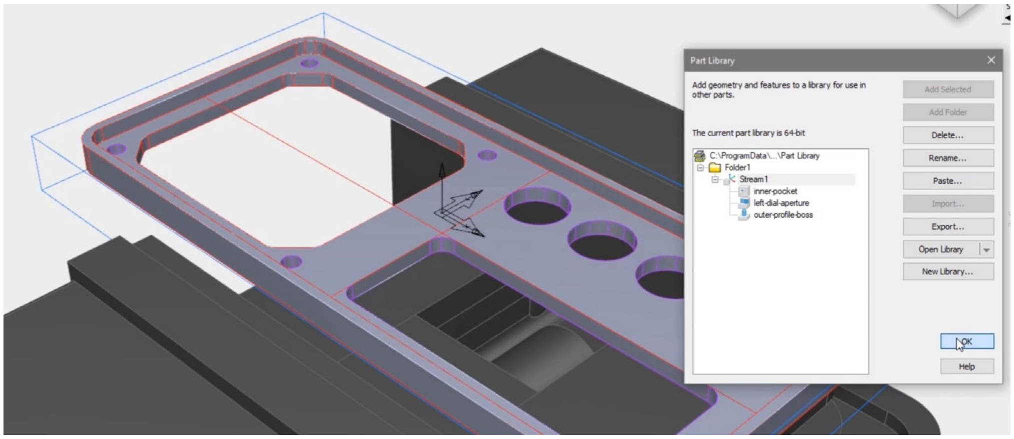


Figure 23 - Part Family Features Reused from FeatureCAM Part Library

Automated Part Setup & Verification

Any area where a manual process is used, is an opportunity for the introduction of automation.

The manual setup of a part is one such example. When we place our stock material, or our part processed mold tool on the machine, we will obviously need to tell the machine where the work coordinate zero position is located, relative to what we want to machine.

This process is difficult to do manually, carefully jogging the machine, clocking the stock or mold in order to position as accurately as possible, and because it is difficult, it is time consuming. The knock-on effect is that the machine is under-utilized, sat idle, and not cutting parts, which eats into profit margins.

And what if the mold is taken off the machine, for example for in-process inspection, and further work, or rework is required? The mold must be repositioned again, adding more time to the manufacturing process, with the issues of setting up manual being compounded further by the difficulty to repeat the previous setup process exactly. The result is that part accuracy suffers.

To combat this, we can automate the setup process and verify as we go.

It is not uncommon these days for machine tools to come with probes included, and probes can also be easily retrofitted to many machines, and it is the combination of these probes, and the software to create measurement sequences, which allow both the automation of the setup process and the verification of machined molds (or any part for that matter) to be performed.

This means complex free-form and prismatic parts can be quickly checked with the capability to perform this in multi-axis orientations. And there are many benefits. Automating setups significantly reduces the time it takes to set up a part on the machine, and once a sequence is created, since it runs as NC code, it is both repeatable and consequently more accurate than a manual setup.

The result is that the machine tool capacity is utilized for production, not wasted through workpiece setup. Additionally, using the probe to verify the part, whilst still on the machine, maximizes machine productivity further, and reduces the potential for expensive post-machining rework. As a consequence, the mold accuracy is improved, which has a direct effect on the accuracy of the final parts it makes.

To test this, we asked a machine operator to perform 2 setup sequences on a generatively designed version (which we'll go into later) of the performance car suspension upright component.

Figure 24 - Manual vs Automated Part Setup on a CNC Machine Tool

In *Figure 24*, the left image shows the manual setup process, and the right image shows the automated setup process.

Even for an experienced operator, this process is difficult and time consuming to do manually, using tools such as digital test and coaxial indicators, and z-axis presetters to locate the part, all whilst carefully jogging the machine, and adjusting the part to position it as accurately as possible. The result, is that the machine is under-utilized, sat idle and not cutting parts, which eats into profit margins.

Automating the process with the use of software and a machine tool probe combats this. By programming setup sequences offline, and running them as quick, repeatable, and accurate NC-programs, profitability can be maximized, as machine time can be better utilized for production, rather than wasted through workpiece setup.

Even in this simple example, the manual setup takes 15 minutes 10 seconds, whereas the automated setup takes just 2 minutes 40 seconds, representing an 82% saving of time on the machine. So, to maximize your machine utilization, and increase part accuracy, using an automated setup process becomes an obvious choice.

Revisiting our mold tool then (see *Figure 25*), automated part alignment can be used to produce quick, accurate and consistent setups, with part verification (whilst the component is still on the machine) being used to check accuracy before moving to subsequent operations or final inspection.

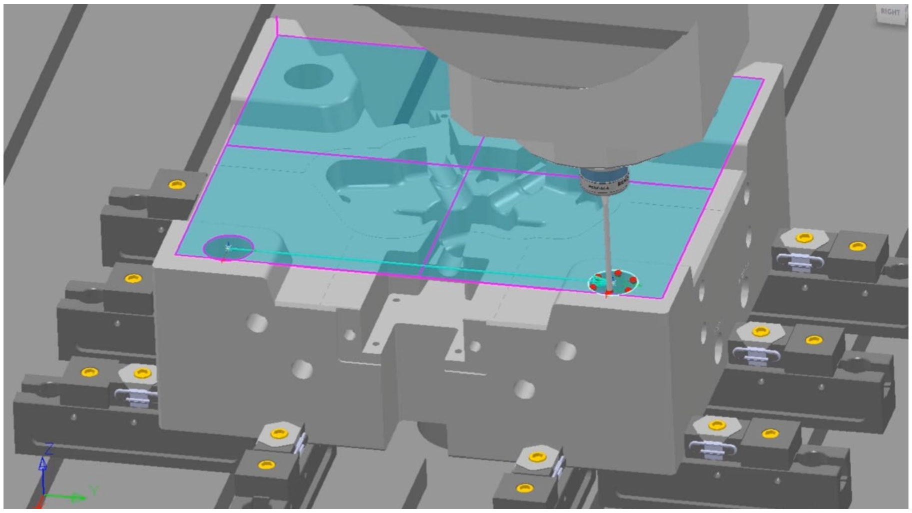


Figure 25 - Automated Setup and Part Verification in Autodesk PowerInspect

Any unexpected variation can be detected and remedied immediately, minimizing costs and improving efficiency, with comprehensive reports providing a record of quality.

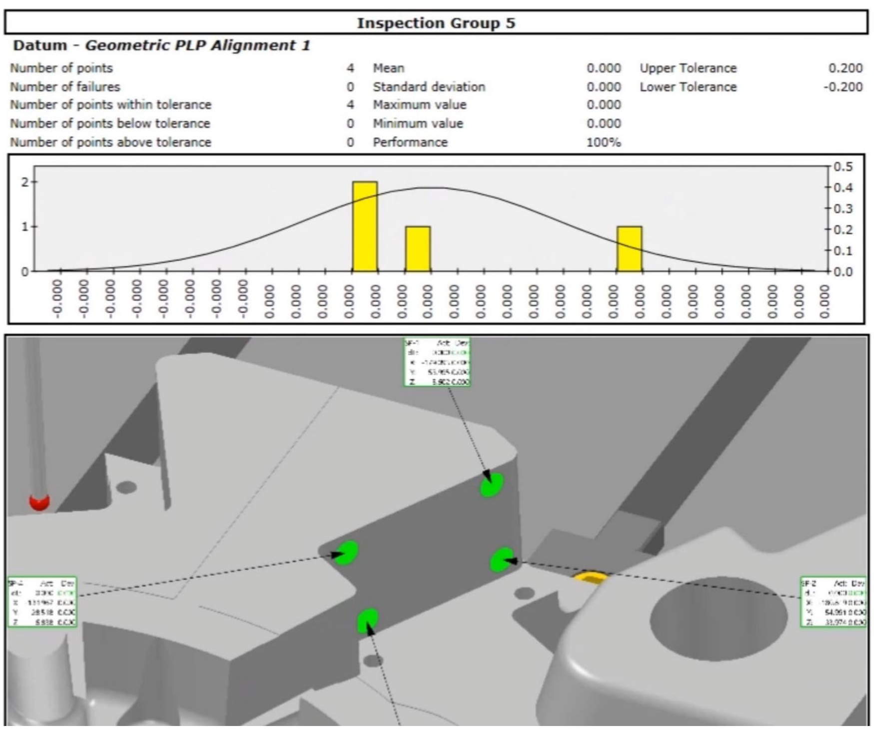


Figure 26 - Comprehensive Inspection Report in Autodesk PowerInspect

Electrode Design and Manufacturing

So, what if we took some of those ideas of automation and applied them to combine workflows? In the final part of this section we will consider Electrode Design and Manufacturing.

For those that are not aware, Electrical Discharge Machining (or EDM) is a process whereby sparks are used to remove material from the workpiece using a tool electrode, within a dielectric fluid (see *Figure 27*).

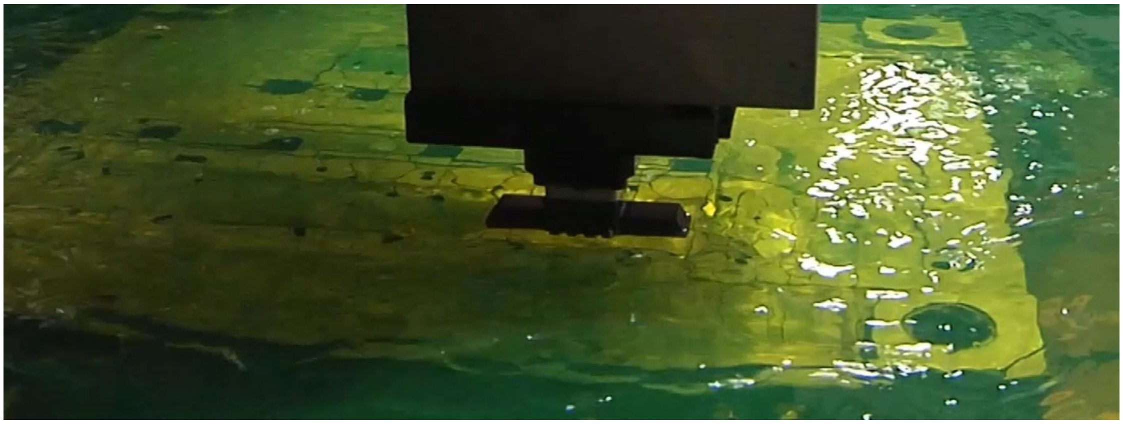


Figure 27 - EDM on a Large Mold Tool

In the case of mold tools, EDM is used to add detail to the mold, where conventional machining cannot be used. But it's not without issue, and there are some challenges to overcome.

Measuring the electrode accuracy can be difficult, as the comparison of the machined electrode must be made to the actual electrode size allowing for spark gaps, and not the final feature size in the CAD data. Tool wear, setup and machining deflection can affect the final results, so adjustments must be made in the electrode use for higher accuracy spark erosion.

EDM machine data entry is also an issue. This is traditionally a manual process, and can be subject to human error when data is manually entered into the machine. Mistakes at this stage, on a near finished automotive mold tool, can prove very costly.

When it comes to the application of software for EDM, there are 4 key stages (see *Figure 28*).

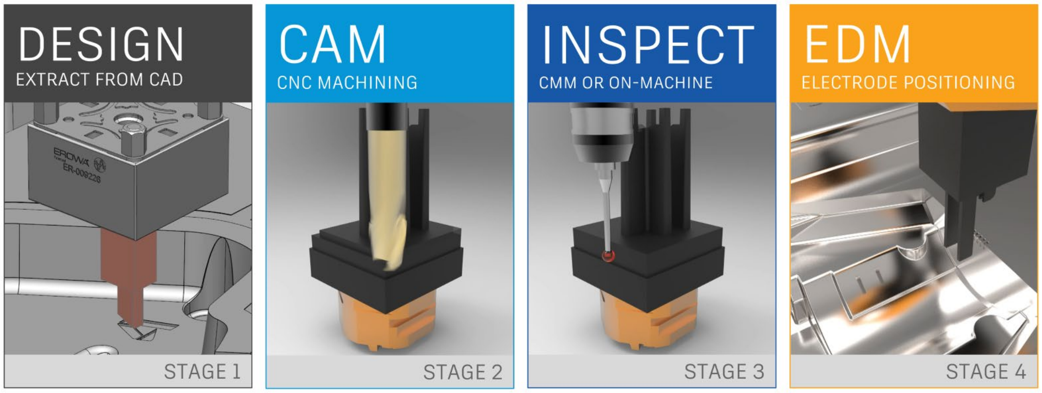


Figure 28 - Key Stages of EDM Software Application

1. The first is the electrode design itself, where the electrode form must be extracted from the mold tool CAD model.
2. The next is using CAM to define the CNC toolpaths to machine the electrodes.
3. Next, we would need to inspect the electrode, on either on the machine, or on a CMM.
4. And finally, we have the EDM process itself, where the pre-defined positioning and EDM parameters, are used to machine the mold.

So, how does software help here?

The electrode design must be extracted from the mold tool form. This can be done with conventional modelling techniques, as well as direct modelling, and assembled with the desired electrode holders. Measurement sequences can be defined at the design stage too, as well as customisable EDM data including start and end positions, burn vectors, spark gaps, rotation, material and so on, and automatically entered into a text file for use on the EDM machine. This can be packaged up into a single file and moved to the next stage in the process.

Based on previous knowledge, the CAM programming of electrode machining can be automated, establishing re-usable templates which can produce consistent, repeatable results.

Measurement sequences (defined at the design stage) can take into account parameters such as spark gaps, for accurate electrode measurement. The inspection results based on the inspection for each electrode can also update the electrode use information, so that the most accurate information is used automatically.

The text file of electrode use information (also defined at the design stage) can then be easily transferred the to the EDM machine controller, avoiding the chance of the human error, associated with manual data entry.

All of which combines into a closed-loop workflow between electrode design, manufacture and metrology.

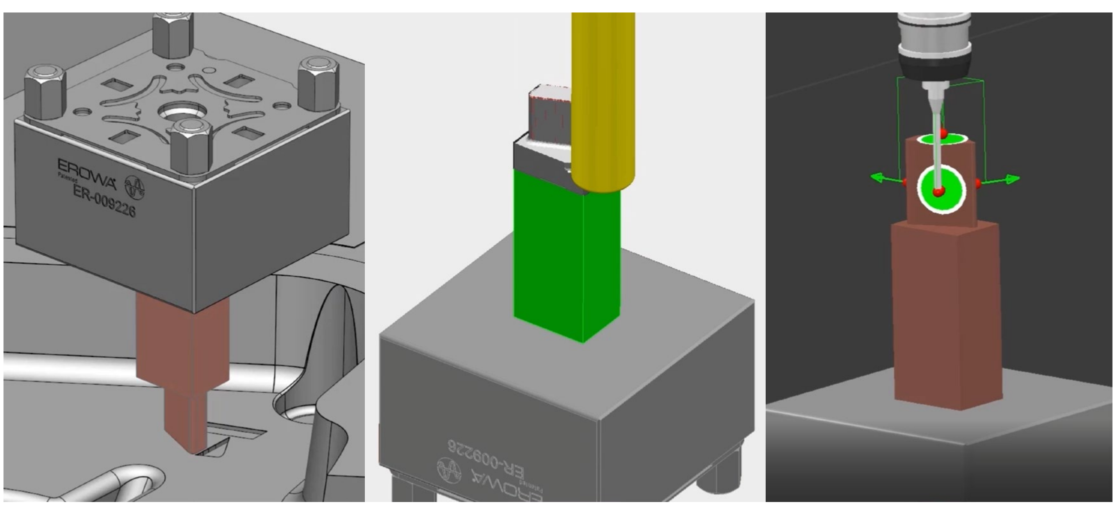


Figure 29 - Design, Machine and Inspect in a Single EDM Workflow

Emerging Technology

Automotive manufacturers are under constant pressure to improve the performance and efficiency of their vehicles, in order to meet global sustainability and regulatory requirements.

Better mechanical performance, reduction in mass and reduced emissions are all critical. Because of this, automotive manufacturers are constantly looking to new design and manufacturing technology to address these pressures.

Traditional Approach

Now before we look at some emerging technology, let's understand where we are coming from, by looking at a traditional approach to manufacturing a part.

When we think of the traditional approach to manufacturing serviceable components, we may think of molding, casting, forging and so on, especially when making mass production parts. In this example we'll consider the performance car suspension upright in *Figure 30*.

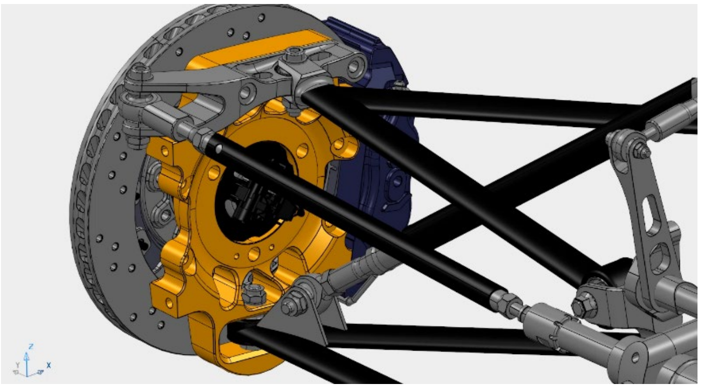


Figure 30 - Performance Car Suspension Upright

How might we manufacture *this* part? What do we need to consider? The part must obviously be accurate, and its function suggests that we need a material capable of withstanding the loads. Since the car is a performance car, then it is likely to have a smaller production volume, and so maybe we want to avoid the costs of creating tooling?

One answer might be to take the design as it is and machine it from billet to achieve the desired shape, followed by an inspection processes to verify part accuracy. All of which is a perfectly valid approach, taken by manufacturers all over the world.

But what if the requirement was for the same mechanical function and equivalent mounting size, but with a reduction in component weight, or consolidation of assembled parts?

Generative Design

Let's take a step back for a second, look at how a part is conceptualized, and introduce generative design.

The future of automotive engineering design, where customers look for more, with better performance, and yet with less negative impact on the world, brings about exciting new opportunities for us, in design and manufacturing. But that also means there are challenges we need to overcome.

When designing automotive parts, we often have limited time to conceptualize ideas. Our teams are constrained by the engineering expertise within them. Downstream processes might not be considered during design and late-stage changes are costly.

So, what if complex design and engineering challenges could be solved with 1 designer, in hours rather than days or weeks and at a fraction of the cost with Autodesk generative design?

What is Autodesk Generative Design?

Autodesk generative design is a design exploration and manufacturing solutions technology that gives you the power to simultaneously generate multiple CAD-ready solutions based on real-word manufacturing constraints and product performance requirements. Generative design allows you to fully explore the design space through consideration of multiple materials and manufacturing methods and how these are able to affect the design.

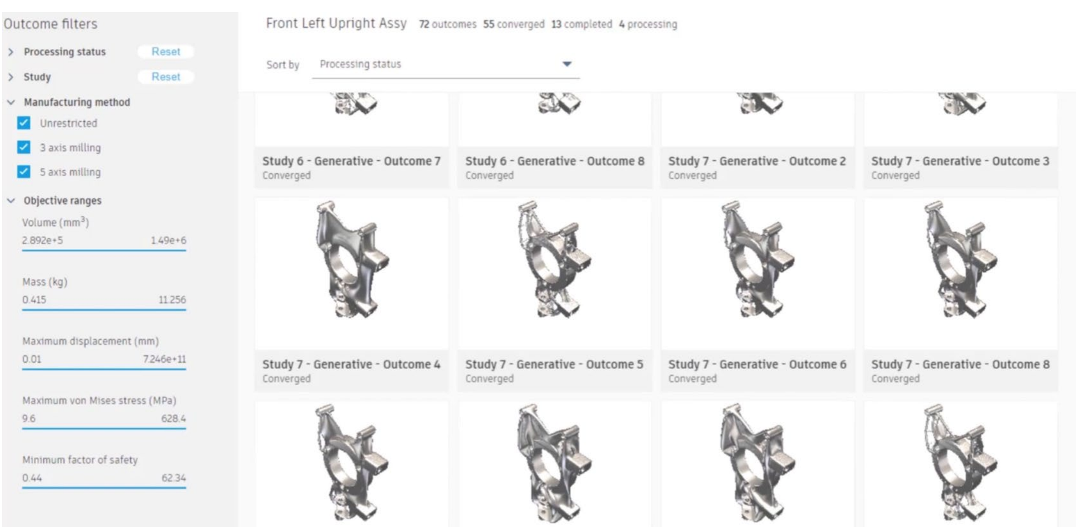


Figure 31 - Generative Design; Multiple CAD-Ready Solutions

It allows designers and engineers to solve problems the way we were trained, allowing us to focus on mastering the problem, such as:

- What are my performance criteria?
- What constraints need to be considered?
- What are my fabrication options?

And then letting the computer do the CAD work.

So, what are the typical project objectives? In some cases, automotive companies are using it purely for innovation, for example creating more manufacturing-aware design ideas up front. In other cases, they are looking for better performance, lighter vehicles, stronger components, better energy efficiency, using less natural resources, and so on. Some are looking for process improvements, eliminating re-work and speeding up the product development process, and others, of course, are looking to reducing costs.

How is Autodesk Generative Design Different?

Well firstly, there is no one single answer, but rather multiple outcomes, that all meet your criteria (see *Figure 31*), which are all influenced by the manufacturing constraints you apply.

So maybe you have access to 3D printers and additive manufacturing expertise in house, or perhaps a casting facility you work with, or maybe you are doing more CNC work? Generative design can produce outcomes to meet any of those fabrication options.

Figure 32 show how the traditional design process can lead to numerous iterations, feedback cycles and restarts, which elongates the time to manufacture.

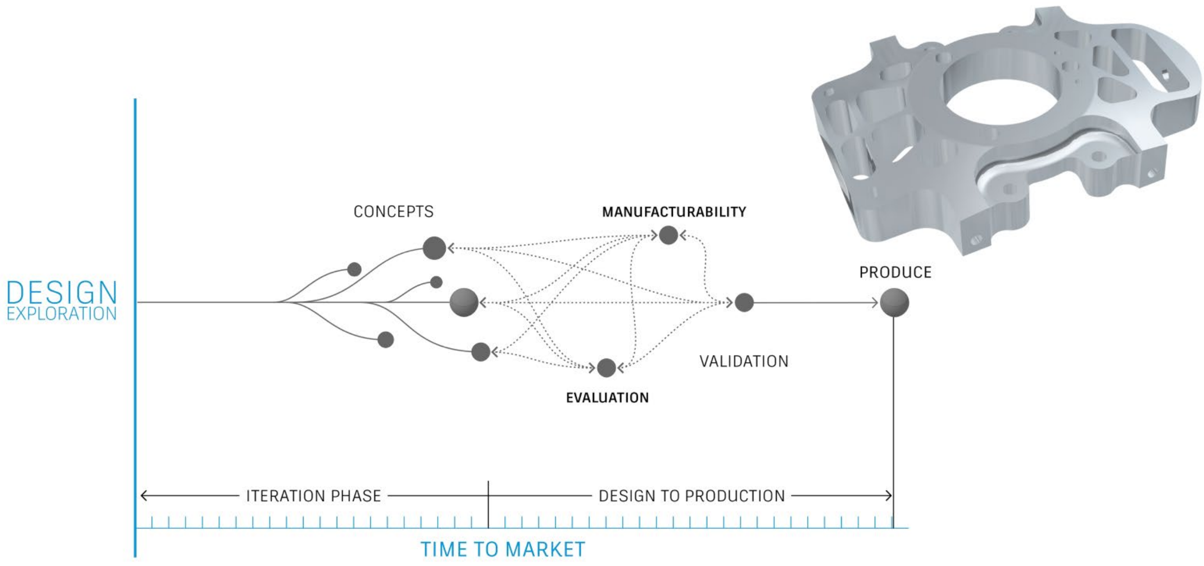


Figure 32 - The Traditional Product Development Process

Figure 33 shows how the hundreds of viable, CAD-ready design solutions you get from generative design, to choose from at the start, amplify your team's ability to innovate and get to market faster. It enhances human talent with technology, uniting designers with machine learning tools and cloud computing power, creating a whole new way to solve problems.

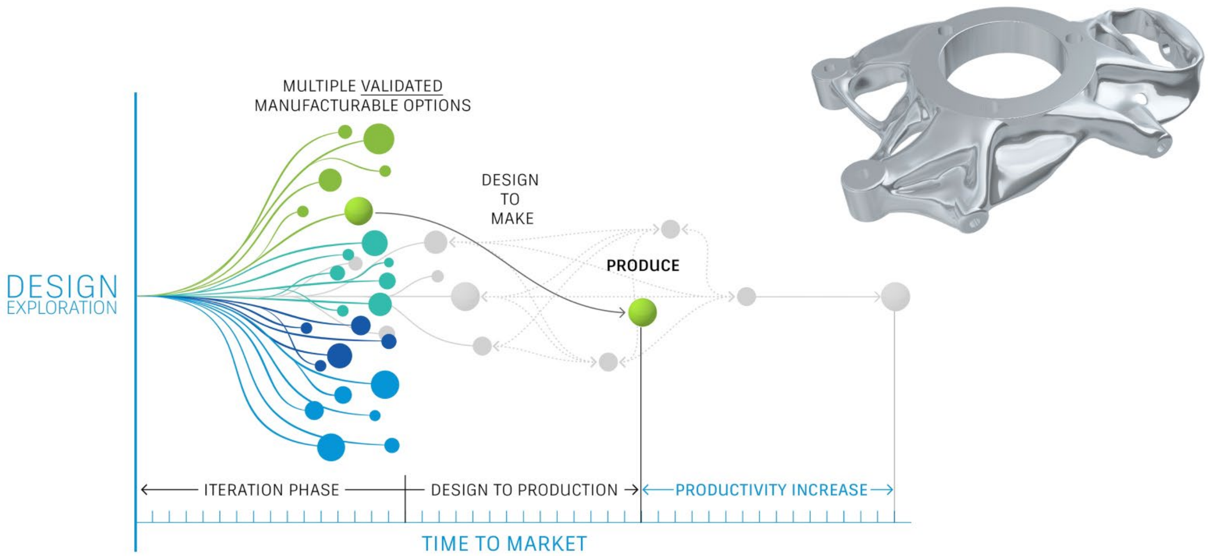


Figure 33 - Productivity is Improved with Autodesk Generative Design

Generative Design was therefore used to redesign our suspension upright, which was then subsequently machined using a range of high-speed roughing techniques, and comprehensive 3-axis and simultaneous 5-axis finishing operations (see *Figure 34*).

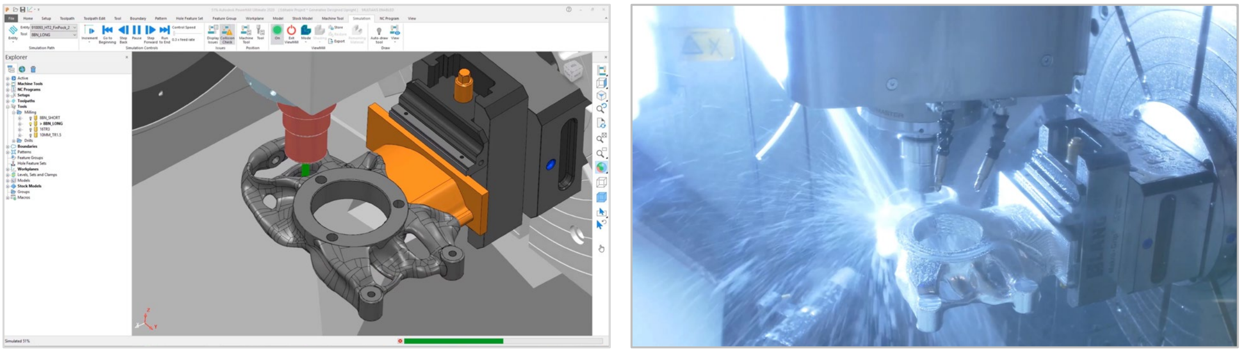


Figure 34 - CAM Programming in PowerMill, and the Part on the Machine

Additive Manufacturing

We've seen how generative design can change the way parts are designed, but what about the way parts are manufactured? We still have some scope to improve part performance after design, so how can our manufacturing method help improve performance? What new challenges might we have to face if we change the way we manufacture a part?

In terms of challenges, we may need to address more complex parts, which would be difficult, or even impossible to manufacture using traditional methods. We could be faced with shorter lead times, which might be an issue for things like prototype delivery. Maybe we want to minimize the costs associated with creating tooling, and perhaps we want to reduce the labor costs associated with assembly?

So how can additive manufacturing address these challenges? Firstly, additive manufacturing builds parts layer by layer. Because of this, new possibilities open up in terms of the parts that can be manufactured, such as adding complex internal structures that would be impossible to manufacture conventionally.

This means additive manufacturing can exploit lattice optimization, which maximizes part stiffness whilst minimizing mass, by removing unnecessary solid material from parts, whilst assembly components can be consolidated, reducing labor costs downstream.

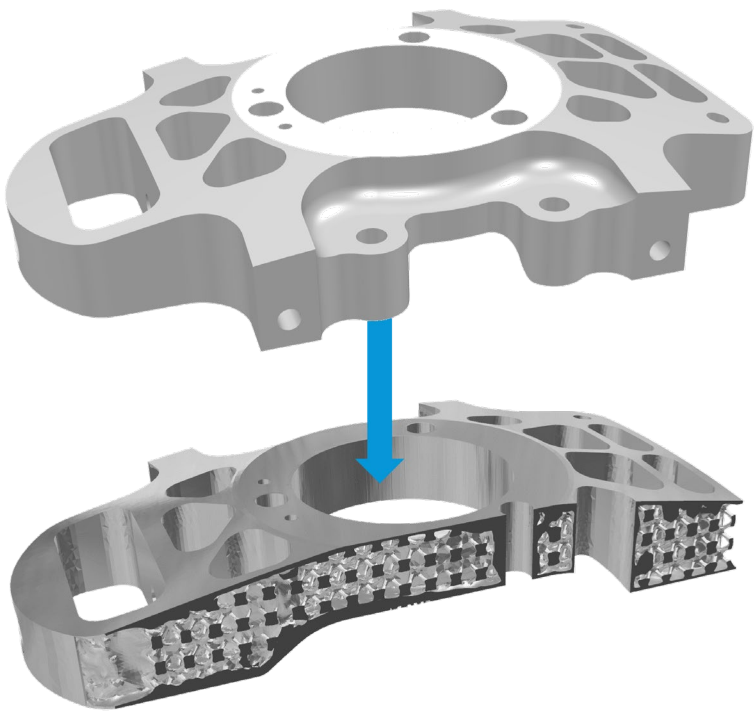


Figure 35 - Lattice Optimization Removes Unnecessary Solid Material from Parts

Because parts are built directly from the cad design, the time to get parts produced in small production volumes is greatly reduced, and without the costs associated with tooling.

What are some of the things we need to be able to do, in preparation of building an additive part, in order to be successful?

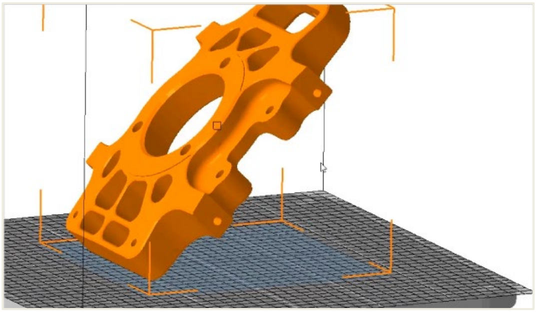


Figure 36 - Orientation and Nesting

Orientating and nesting, to ensure parts fit, and maximize the productivity from, the build volume of your machine, is essential.

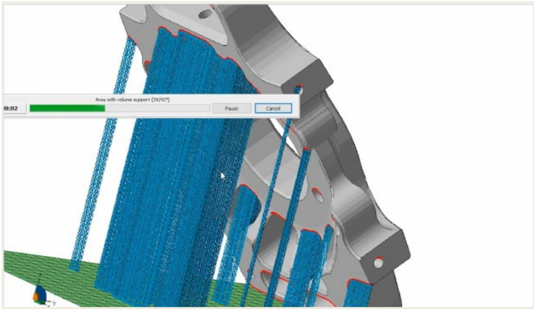


Figure 37 - Part Support

Building supports is required, to temporarily hold the part and minimize distortion during the additive manufacturing build process.

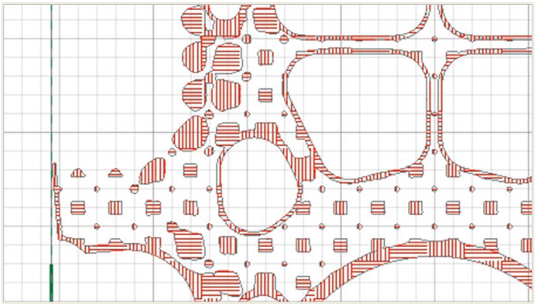


Figure 38 - Toolpath Creation

Accurate toolpath creation for a range of machines is necessary.

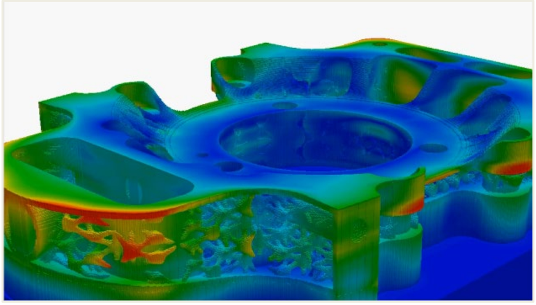


Figure 39 - Build Simulation

Build simulation is crucial to avoid expensive mistakes, such as preventing failed builds.

Hybrid Manufacturing

With additive manufacturing understood, let’s look at Hybrid Manufacturing.

If a part is to be created through additive manufacturing, we might face some additional challenges which need to be addressed. Once printed, additive parts might not have the accuracy we require for the part to be “in-service”. For example, we may require faces to accurately mate to, or seal against, or require accurate threaded regions for secure assembly.

And if we are looking to other manufacturing methods to address these challenges, then extra stock allowances in these areas will need to be added at the design stage. And what if factory floor space is limited? What solutions can we look to?

One answer could be Hybrid Manufacturing. So, what do we mean by “Hybrid Manufacturing”? Whilst I guess the technology, I’m talking about is applicable, I am not specifically talking about the manufacture of hybrid powertrains. What we are actually talking about is the manufacturing of parts with a combination of both Additive and Subtractive manufacturing to achieve the desired part.

The hybrid process gives the best of both worlds. Solid parts can be replaced with hollow components containing internal latticing which are much lighter, deliver the desired strength and ultimately improve product performance, but they can only be produced using additive manufacturing. To compliment this, printed parts can then be quickly and easily machined, for accurate final finishing.

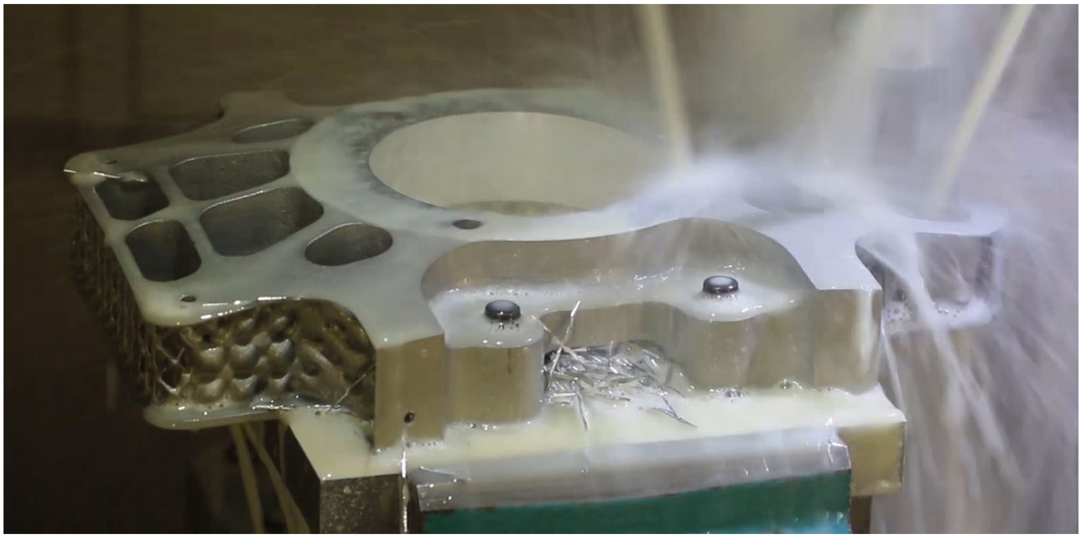


Figure 40 - Additive Part, being CNC Machined in a Hybrid Manufacturing Process

Results

In terms of the automotive upright, we manufactured these parts ourselves, in one of our Autodesk Technology Centers, and it is worth looking at the results, to see a direct comparison between them (see *Figure 41*).

Bearing in mind all components were made from Aluminium, the original design (subtractively machined from solid billet) had a mass of 1693 grams. The generative design (also subtractively machined from solid billet, though requiring more complex, simultaneous 5-axis machining), had a mass of 1365 grams – a 19% saving. The latticed, hybrid part, had a mass of 924 grams, which represented a 45% saving, and the last part, which combines both a generative design, additive and latticing, had a mass of 692 grams, a 59% saving.

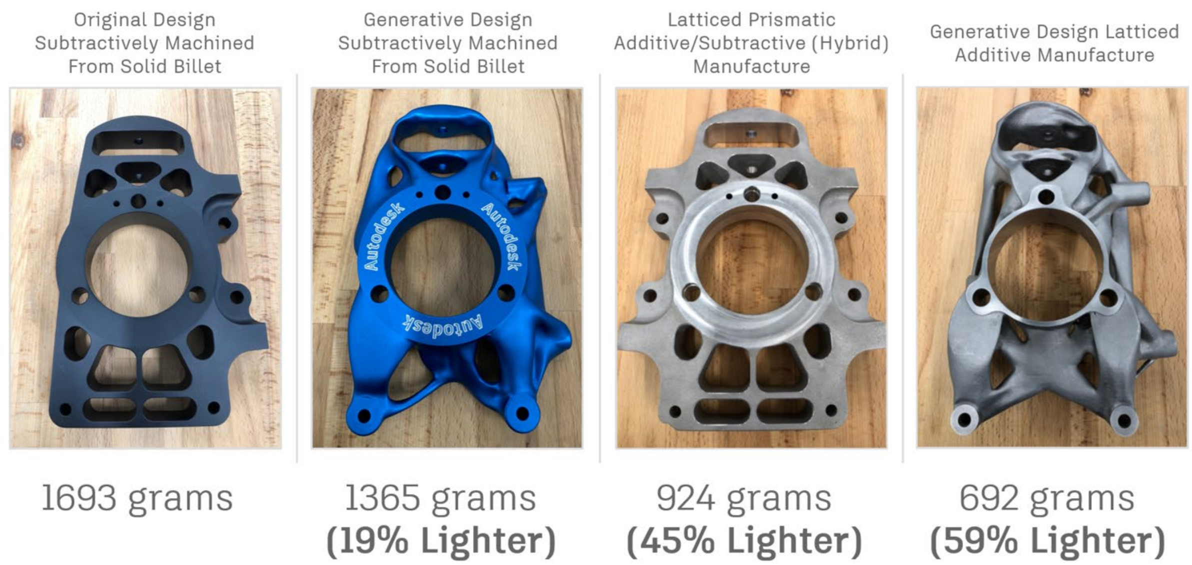


Figure 41 - Suspension Upright Results Comparison

From the first to the last part, lateral stiffness went up from 59kN/mm to 186kN/mm.

Whilst there are some variations in part design due to our own experimentation (the obvious one being the reversible symmetry of the hybrid part), there are clear benefits to these approaches, when talking about component performance.

Conformal Cooling

You'll remember at the beginning we looked at mold simulation to improve the part design. So how can this disruptive emerging technology be introduced into our process? Let's go back to our water pump mold again and look at conformal cooling.

Molds are traditionally cooled (see *Figure 42*) using simple water circuits, drilled into the steel. These can include baffles and fountains to guide the coolant into more complex areas, but even so, complete cooling can be difficult to achieve with conventional drilling.

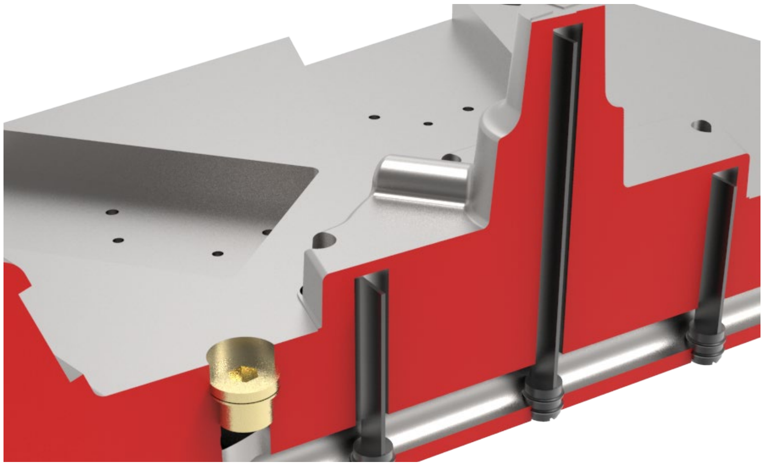


Figure 42 - Traditional Mold Cooling

On our water pump cover, the majority of the heat is likely to be where the part is thicker (see *Figure 42*), at the middle of the part where the ribs meet with the center cylindrical feature, and because the part is also being gated in the center, that is also introducing additional heat, that has almost nowhere to go.

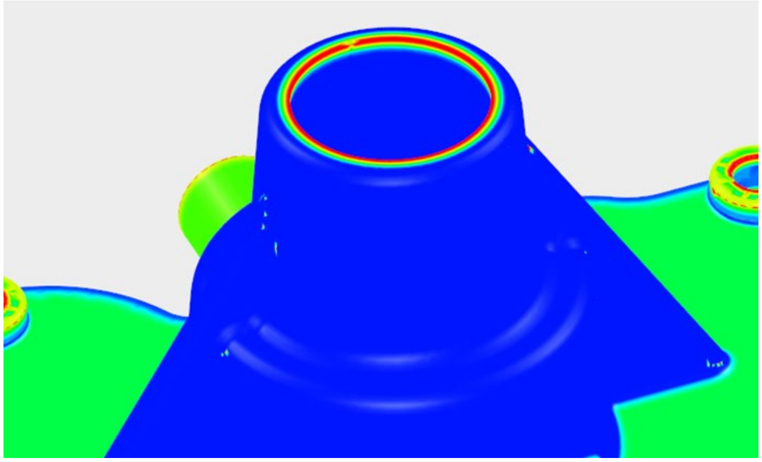


Figure 43 - Thickest Region of the Part

So, can we consider other cooling options? Well we must validate any options to see if the cost of design changes and the method for manufacturing can be justified, by drastically reducing cycle times for example. We also need to think about the additional manufacturing processes that will be required.

One option is conformal cooling, which has recently been gaining more popularity over the past few years. Conformal cooling involves designing the cooling system of either a section of, or the entire mold, where the channels follow the shape of the mold walls to perform rapid uniform cooling (see *Figure 44*).

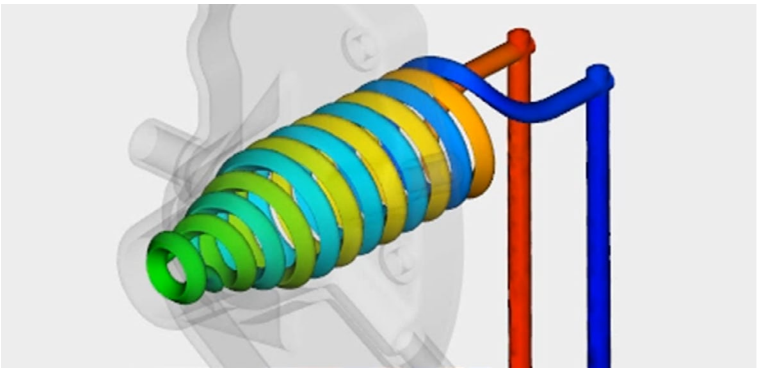


Figure 44 - Conformal Cooling Channel Simulation

So why use it? Well, a molded part's quality is reliant on the thermal history of the polymer at all stages of the molding process, so using conformal cooling to help promote more even temperature distribution within the mold can help to improve part quality, along with other advantages such as optimizing cycle times.

In the past, these types of cooling channels would be manufactured in segments, where an insert may be cut up into several pieces so the conformal sections can be cut out. All the pieces would then need to be matched up precisely and soldered or welded together.
This would be a very time consuming and costly process, all to create a conformal tool that would have a shorter lifespan than traditional drilled channel tools because of the sectioned build being more susceptible to wear and tear.

The growth and improvement of disruptive technology like direct metal laser sintering, has facilitated easier manufacturing of conformal cooling channels within molds, producing a more reliable mold and in fewer steps. But the process can still be time consuming and costly, typically requiring some post-processing such as machining, which is why simulation is used to justify the costs.

Comparing each design (see *Figure 45*), from a simple channel, to more complex machined channels, to the conformal cooling insert, simulation can help demonstrate if conformal cooling can be justified.

In this example, the conformal channels cut the time to reach ejection temperature in the corners in half, compared to a simple channel setup.

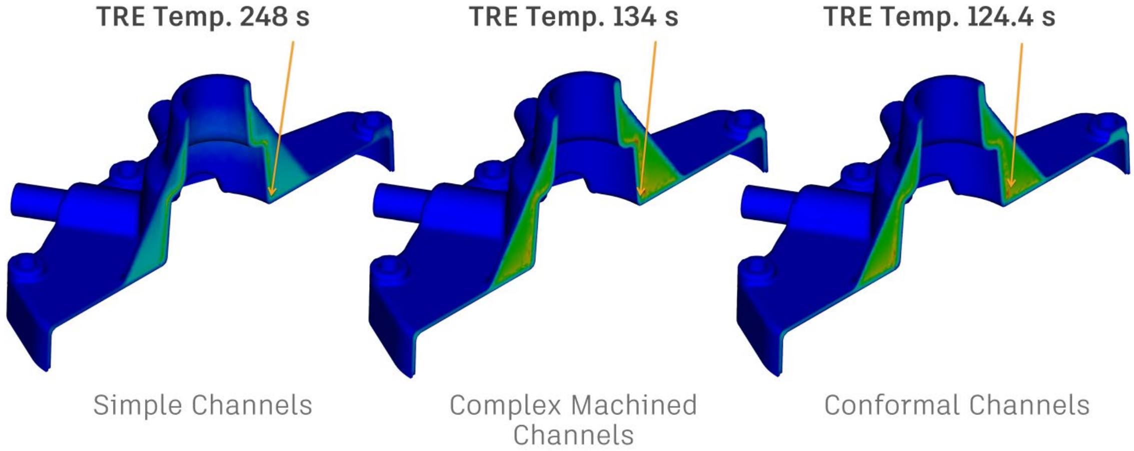


Figure 45 - Comparing Cooling Designs with Simulation

Probing each study in the rib region, at the same interior location for each cooling layout, shows significant differences between the 3 cooling layouts (see *Figure 46*).

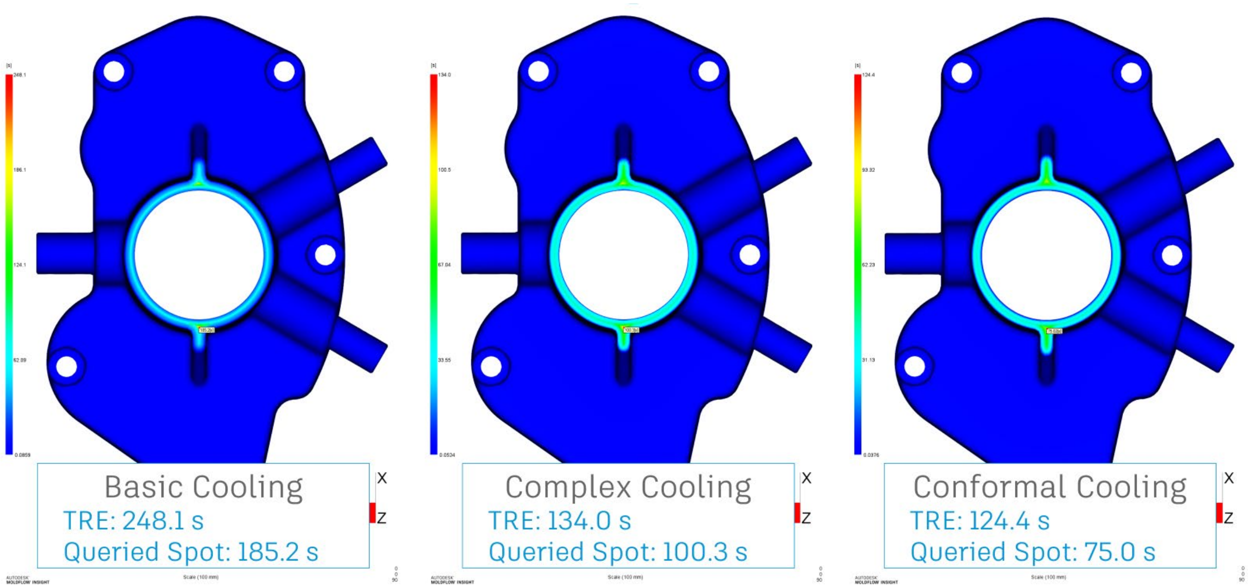


Figure 46 - Comparing Cooling Designs with Simulation with Queried Spot

The savings on the overall cycle time, even between the complex and conformal cooling options, may be enough to justify the cost of using this method over the production life of the mold, but certainly allows us to make an informed decision on whether it should be used.

So, if the simulation result has proved the cost can be justified, how might we manufacture the insert? Well, because additive manufacturing builds parts layer by layer, this makes it ideal for creating the complex cores needed for successful conformal cooling (see *Figure 47*).

Machining allowances can be added at the design stage of the additive build and the result can be finish machined (see *Figure* 49), to achieve the desired surface quality (see *Figure* 49).

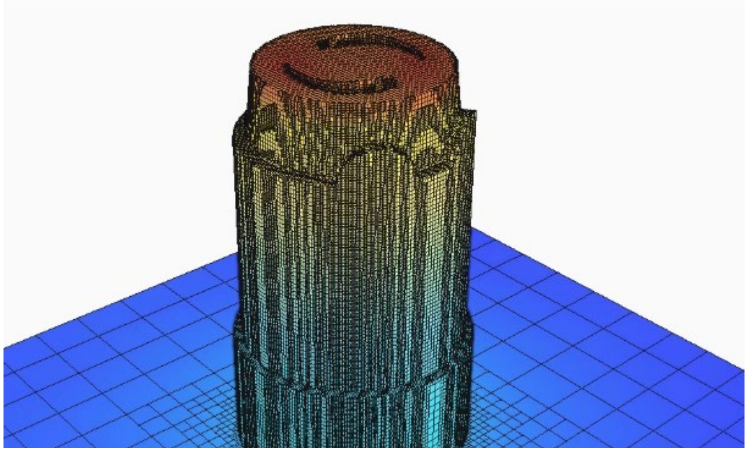


Figure 47 - Layered Additive Build Simulation in Netfabb

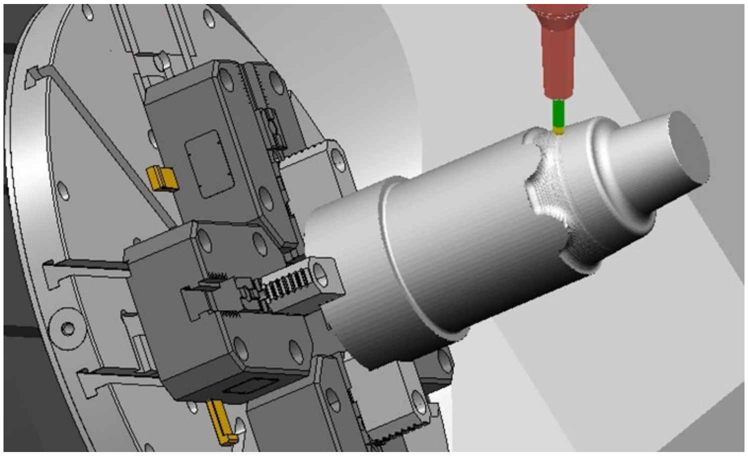


Figure 48 - Mill-Turn Machining in PowerMill

Figure 49 - Finished Conformal Cooling Insert

Additive Repair

It should be noted that, the combination of additive and subtractive processes is not just limited to new part production though. It can also be used for additive repair.

In our mold tool example, it's inevitable that it will meet some challenges in its service. Molds, tools and dies, which have been in constant use, can suffer from wear or damage. Replacing them can be costly, not only due to the costs of commissioning new tooling, but also the loss of production due to downtime.

If we chose to repair the molds, how can we maintain their accuracy and repeatability, and how do we do this, with a growing skills gap relating to the manually intensive traditional approaches to mold repair?

One solution might be to use a high rate additive process such as Directed Energy Deposition (or DED), as part of a hybrid manufacturing process.

DED technologies (see *Figure 50*) such as arc wire, electron beam wire, laser powder and laser wire, can be used to add material to a substrate. Whilst each of these have their own challenges, there are a significant number of common requirements.

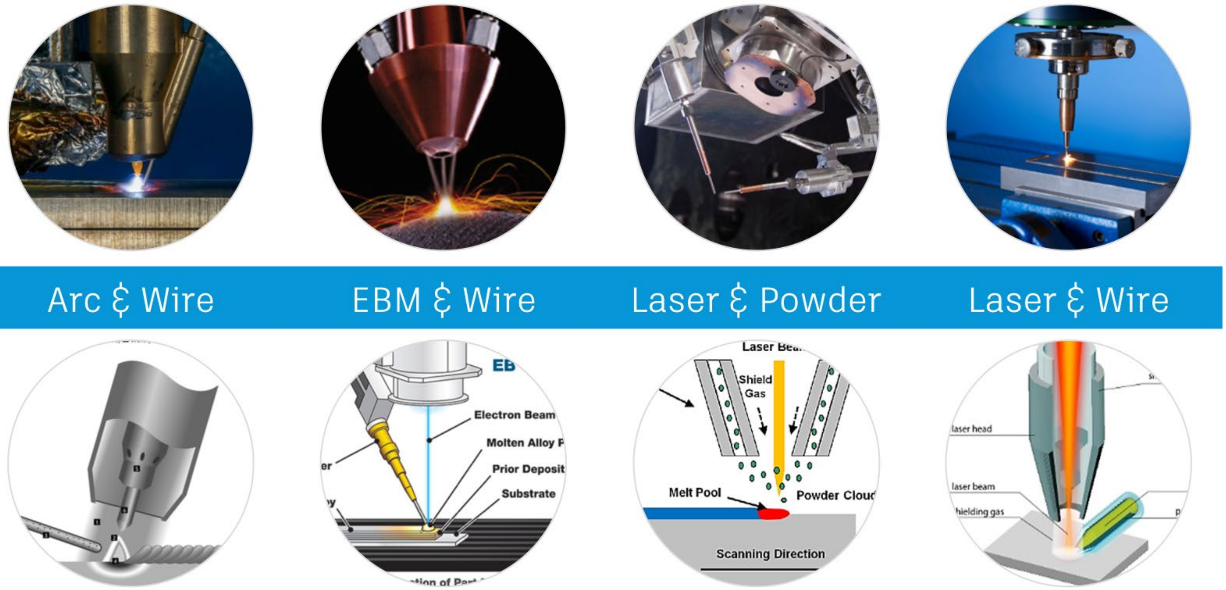


Figure 50 - DED Technologies

The path generation often has similar requirements, with each process requiring control over process parameters such as power and material flow rates.

It is also worth noting though, that high rate additive is not simply the inverse of subtractive. There are various additional constraints that must be considered, for example, toolpaths can never intersect themselves, and the consistency of stepover takes on a much greater level of importance.

But it is this technology (along with traditional subtractive methods) that could be applied to automotive molds, tools and dies, in what is called “non-adaptive repair”, that could be applied in order to rectify damage.

Using a robot with an arc-wire welding head, material can be added to the mold surface to repair damage, allowing them to be recommissioned in a cost-effective way (see *Figure 51*).

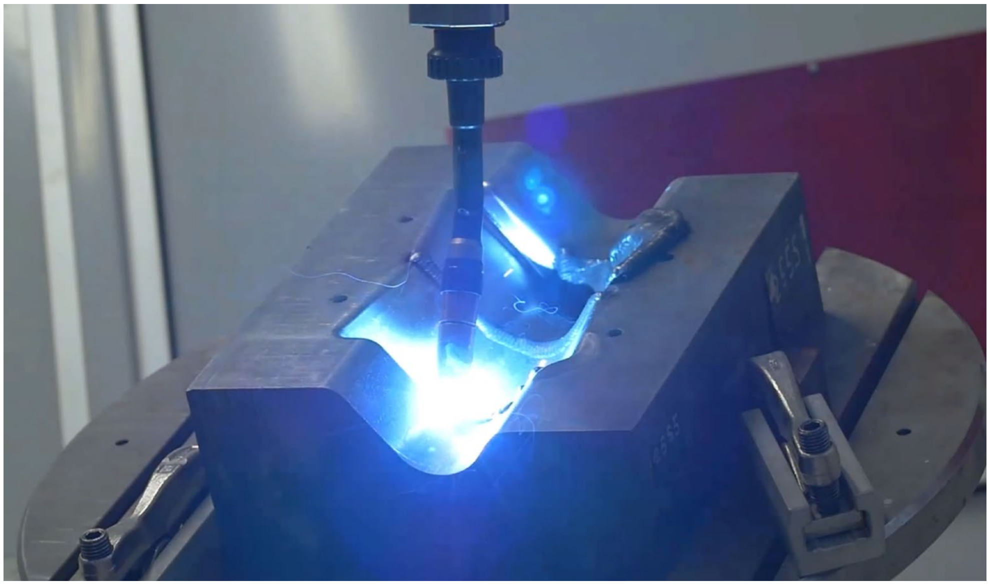


Figure 51 - Robot Welding Mold to Repair Surface

Subsequent subtractive machining removes the excess weld material to return the mold back to its original form (see *Figure 52*).

Figure 52 - Machining Excess Weld Material

And with the growing number of CNC machine manufacturers offering hybrid machines these processes can be combined in a single machine footprint, minimizing setup times, and allowing better utilization of your factory floor space (see *Figure 53*).

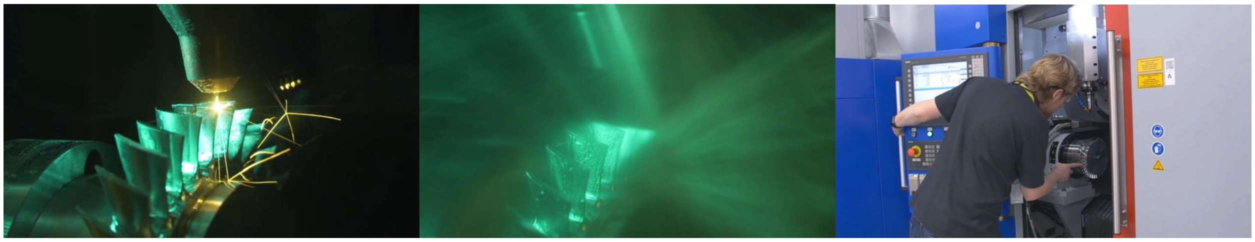


Figure 53 - Blisk Repair on a Hybrid CNC Machine Tool

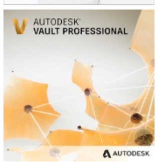
Summary

In this document we have seen how technological software solutions can be used to improve the quality of automotive tooling and the parts they produce. We have seen the challenges that drive change in manufacturing facilities, and how a unified digital model, can be used to manage projects, equipment and production.

We have seen where automation can be utilized in manufacturing processes to improve production consistency, and how emerging technology, such as generative design, additive and hybrid manufacturing processes, can be used to improve component performance and efficiency.

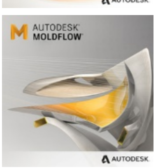
And we have covered a wide range of Autodesk software solutions that can help you achieve this.

Autodesk Product Design and Manufacturing Collection, which includes Autodesk Inventor for CAD design, assembly and tooling modelling, and the Factory Design Utilities, which help you Plan, Commission and Operate your factories.

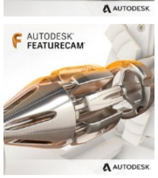


Autodesk Vault Professional to securely manage data, track revisions and collaborate with PDM software.

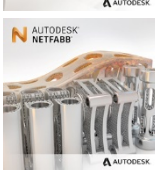
Autodesk Fusion 360 mainly for generative design, but which also unifies design, engineering and manufacturing into a single solution.



Autodesk Moldflow for the advanced simulation of parts and tooling, and the process development of injection and compression molded parts.



Autodesk FeatureCAM for automated CNC programming.



Autodesk Netfabb for additive part manufacturing, lattice optimization and build simulation.

Autodesk PowerShape for mold tool creation and modelling for manufacture.

Autodesk PowerMill for 3 to 5 axis subtractive milling and additive manufacturing using directed energy deposition.

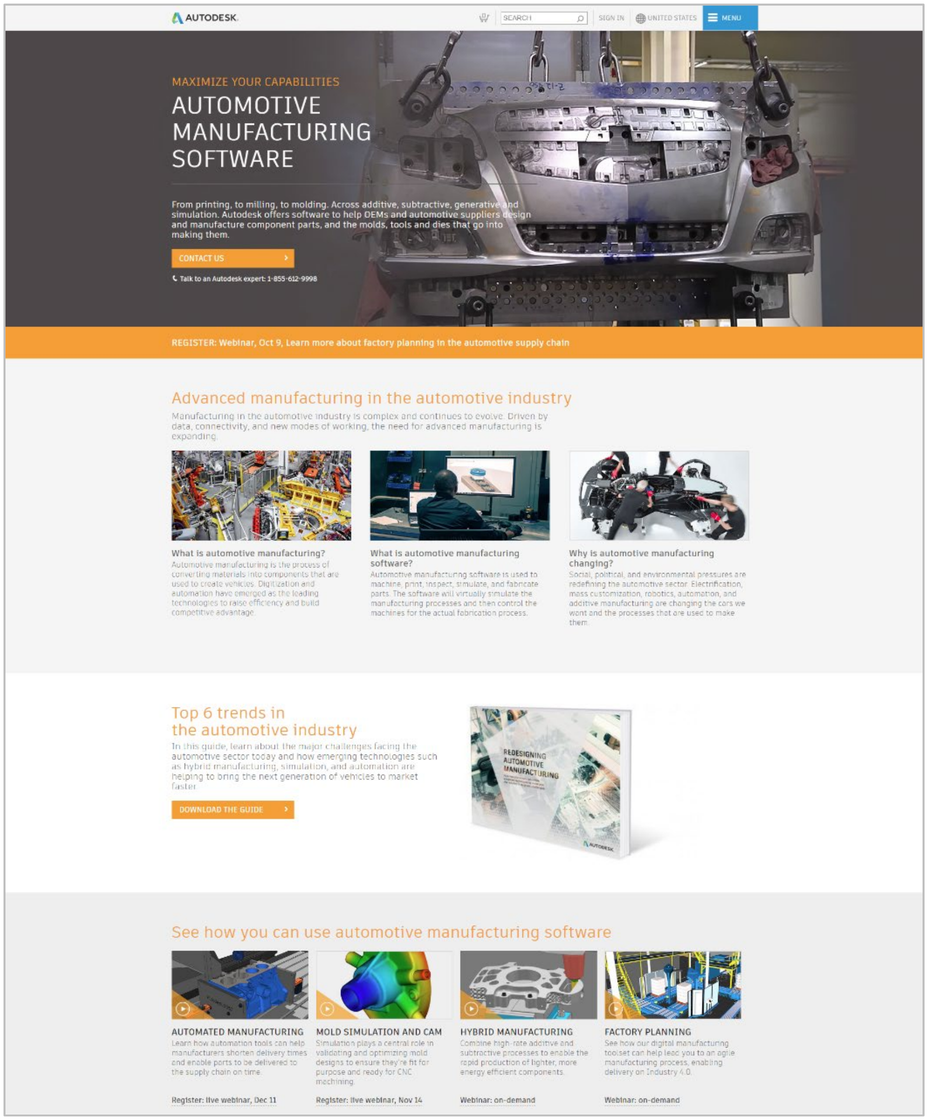
Autodesk PowerInspect for hardware independent automated setup and 3D measurement.

And lastly Autodesk Electrode which combines PowerShape, PowerMill and PowerInspect, to provide a closed-loop system between electrode design, manufacture and metrology.

All of which can help you to make anything.

If you would like to know more information on this subject and on how Autodesk offers software to help OEMs and automotive suppliers, to design and manufacture component parts, and the molds, tools and dies that go into making them, and even design and operate the factories they are produced in, then why not visit the dedicated Autodesk Automotive Manufacturing page at:

http://autodesk.com/automotive-make



And see how Autodesk can help you and your automotive company reach your manufacturing goals.