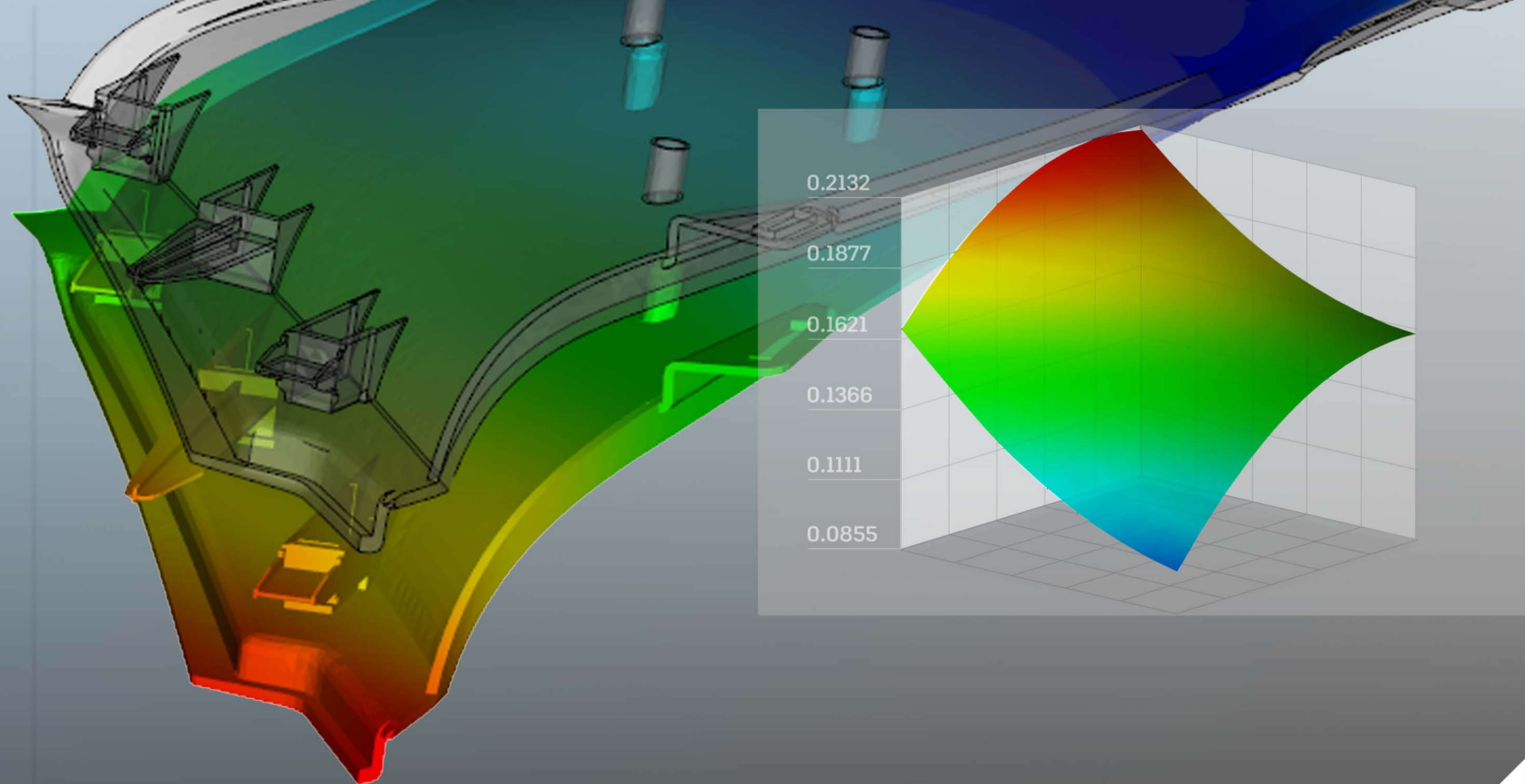

DIALING IN SUCCESS

USING SIMULATION TO OPTIMIZE MOLD DESIGNS AND REDUCE CYCLE TIME

AUTODESK.

INTRODUCTION

The recipe for success

The word “optimization” gets overused in the injection molding industry (and practically every other industry). Companies selling products tend to promise optimized solutions, services, and results. Usually, the word is designed to dress up the reality of “modest improvement.”

In this ebook, optimization has a very specific meaning. It represents the process of adjusting (and readjusting) the variables of a project after the exploration phase is complete and all of the big decisions have been made. The part design, mold, process, and material are not going to radically change course during optimization. But all of the variables within each of these categories definitely can.

Here’s one way to think about it. Exploration is choosing what you’re having for dinner. When exploration is complete, you’ve purchased the ribs from the local butcher shop, dug out your secret sauce recipe, chosen the smoker over the gas grill, and set aside a whole Saturday. Optimization involves all of the little decisions you’ll make along the way to produce the most delicious meal possible.

INTRODUCTION

The recipe for success

This ebook explores the reasons why optimization is valuable to mold engineers, along with three methods for pursuing optimization in a systematic way. For each method, the goal is the same: zero in on the ideal settings for your project and start running parts with confidence.

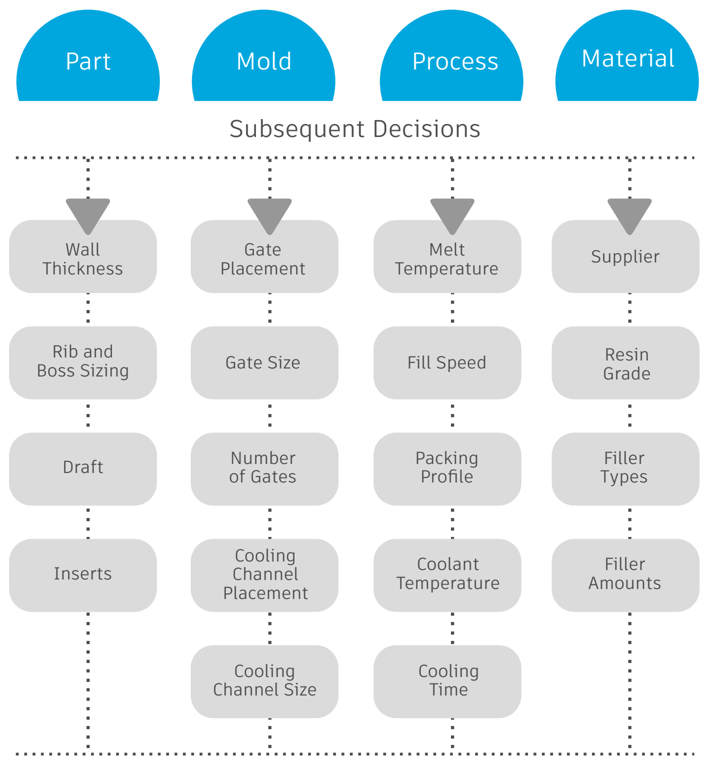

Figure 1: Within each category of "big decisions," there are many variables that create opportunities for optimization.

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WHAT IS OPTIMIZATION?

Optimization helps mold engineers adjust the right variables in a project to deliver the best possible outcome with the lowest cycle time.

WHAT IS OPTIMIZATION?

Small decisions, big results

From the mold designer's perspective, the pursuit of the perfect part has two phases. The first phase covers all the big decisions about part design, material family, process type, and cooling method. The second phase covers all the small decisions within each of these categories.

This is the essence of optimization: making small adjustments in an iterative fashion to generate the greatest value from your setup. In other words, you're tweaking the variables until they are just right. Optimization may lead you to redesign one element of the part to align with the process, evaluate different grades of the same material, fine-tune process settings to minimize cycle time, or alter the placement of cooling channels to create a more uniform temperature.

Optimization is valuable precisely because these relatively minor adjustments can deliver significant results for the project and your organization. The choice between different grades in the same resin family could affect cycle time enough to save hundreds or thousands of hours of runtime for high volume production. When you are manufacturing millions of parts, opting for a 1.3mm wall thickness instead of a 1.5mm wall thickness could save a half-gram of material and a full second of cycle time, leading to big bottom line savings.

WHAT IS OPTIMIZATION?

Small decisions, big results

Keep in mind, “optimized” always begs the question: optimized for what? As mold engineers know, there is no universal “best” design for any injection-molded plastic part. The best design is one that meets your specific requirements, which are subjective. While there will always be quality thresholds to meet, your top priority may be cycle time, or cost, or surface finish quality. There will always be tradeoffs. Optimization helps you untangle these relationships to keep your priorities in balance.

When that happens, you can find the settings that help you meet the requirements that are most important for your project with the shortest cycle time possible.

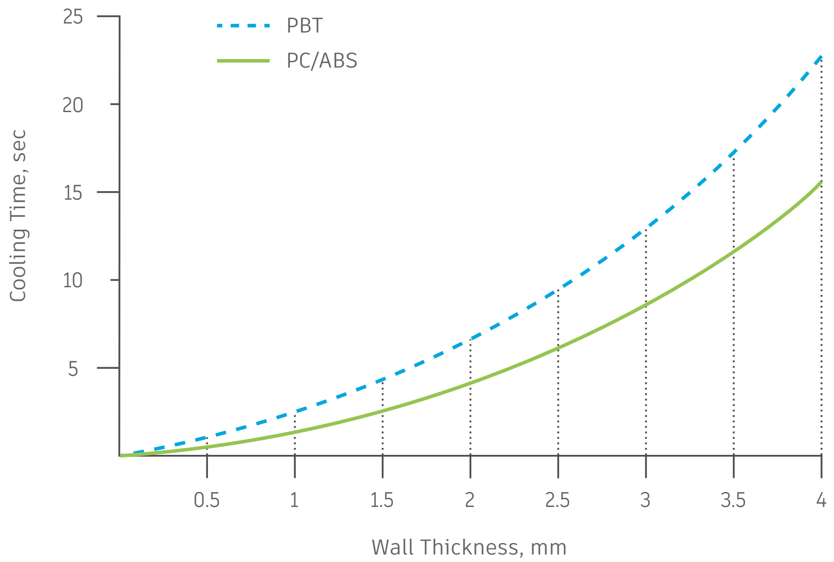


Figure 2: Comparing incremental changes in wall thickness for two materials allows you to find the optimal cooling time.

SCOPING THE CHALLENGE

Optimization is an inherently complex exercise that requires a systematic plan to avoid the risk of unproductive, open-ended investigation.

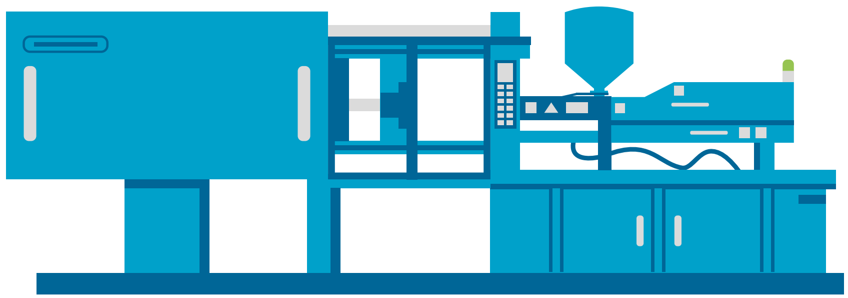
SCOPING THE CHALLENGE

Caught in a web of complexity

Injection molding isn't just a complex process. It is likely the most complex of all widely used, high-volume manufacturing processes. Within each of the four major factors in every project (part design, material, process, and mold design) there may be a dozen or more variables that can dramatically affect the outcome. Many of these variables are directly connected to others, both in ways that are obvious and those that are not.

This complex network of interrelated variables is what makes optimization so difficult. Obviously, making a big change, such as selecting a new material, affects everything about the project. But other interactions are counterintuitive. Within a single category, for example, changing one variable can simultaneously have the intended result as well as an unintended consequence that compromises a different variable.

The nature of this complexity is what makes it vital to have an optimization plan. Without a systematic way to understand the variables under consideration, mold engineers run the risk of "wandering around" in the design space reacting to results as they happen. Instead of converging on a solution that fits specific criteria, you diverge outward. When time runs out, the temptation is to settle on the most recent design, which may not necessarily be the best one.



SCOPING THE CHALLENGE

Caught in a web of complexity

Here's an example. Let's say you change a process setting to reduce the cycle time, such as lowering the temperature of the coolant. This does what you wanted: cycle time is shorter. But now the mold is not completely filling, resulting in a short shot. Next, you try increasing injection speed to maintain the lower coolant temperature and still fill the mold completely. But that causes another unintended result and the cycle repeats, even though the right answer is that you should not have changed the temperature of the coolant in the first place.

Creating an optimization plan helps avoid following a random, tangential path from outcome to outcome. By identifying the key variables for your project, you can construct a scientific way to evaluate their interactions and effects on the desired outcomes in a much more efficient way.

OBJECTIVE: Minimize cycle time

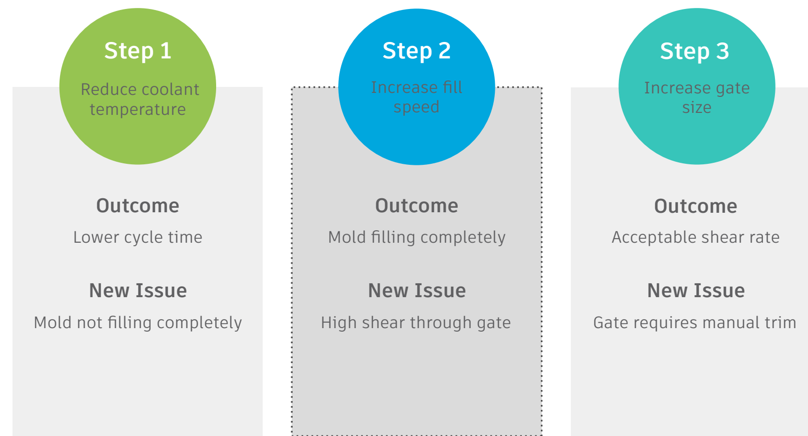


Figure 3: Changing processes without a plan can create a chain reaction of unintended consequences.

KEY VARIABLES

Differentiating the two categories of variables can help you set priorities as you develop an optimization plan.

KEY VARIABLES

Adjust your expectations

Before you can develop a plan for optimization, it's important to quickly recognize the two categories of variables that can be optimized: geometric variables and process settings.

Geometric variables are those that can't easily be changed after the mold is made. In other words, these are the factors that define the geometry of the part or the mold. Once the mold is drilled or milled in accordance with these parameters, changes become extremely expensive to make.

Examples of geometric variables include the wall thickness of the part, cooling channel placement and sizing, and the type, placement, size, and number of gates. (While it's true you can adjust gate size after the fact, they can only be made bigger. So it's still important to get this right the first time.)

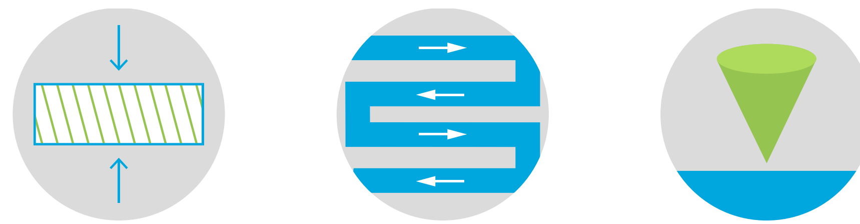


Figure 4a: Geometric variables are those that establish the geometry of the part or mold.

KEY VARIABLES

Adjust your expectations

Process variables are comparatively easy to change after the mold has been manufactured. In some cases, as with packing pressure, process settings can be gradually adjusted during the run to achieve an operational goal, such as reducing warpage. That being said, mold engineers can save a great deal of time by optimizing these settings before the mold is in the press, rather than spending the time to fine-tune them when you could be running parts.

Examples of process settings include the packing profile (pressure and time), injection speed, melt temperature, and coolant type and temperature. Specialized molding processes typically have their own individual settings, such as gas pressure and injection time for microcellular injection molding.

Figure 4b: Process variables can easily be adjusted after the mold is complete.

THREE APPROACHES TO OPTIMIZATION

Executing optimization can be done in several ways, all of which involve simulation, and each of which is suitable for a different type of project.

THREE APPROACHES TO OPTIMIZATION

Picking the right path

In general, there are three ways to optimize the variables of injection molding, all of which involve simulation software. (The rest of this ebook will spend more time describing each one.) The approach you choose will depend on your schedule and budget, as well as the capabilities of your software tools.

1. Design iteration

With this method, mold engineers make changes to the geometric variables or process settings manually. After each iteration of change, you can compare the outcome to previous results to identify whether the desired effect has been achieved.

1. Create baseline part and mold geometry
2. Run initial simulation
3. Use results to inform possible design improvements
4. Modify part and/or mold geometry
5. Rerun simulation to determine impact

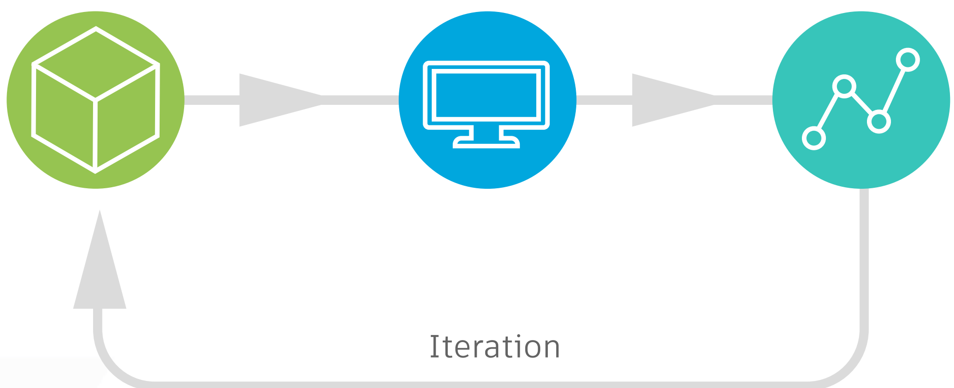


Figure 5a: An example of a typical design iteration workflow.

THREE APPROACHES TO OPTIMIZATION

Picking the right path

2. Parametric optimization

Parametric optimization focuses exclusively on geometric variables. It offers an automated way to adjust these factors and run a series of analyses to investigate the impact—without changing the original CAD design and reimporting the model each time.

1. Create baseline part and mold geometry
2. Choose the geometric parameters to be modified
3. Determine the range for each parameter
4. Setup and run analyses in parallel for each combination of variables
5. Identify the best result and update CAD models

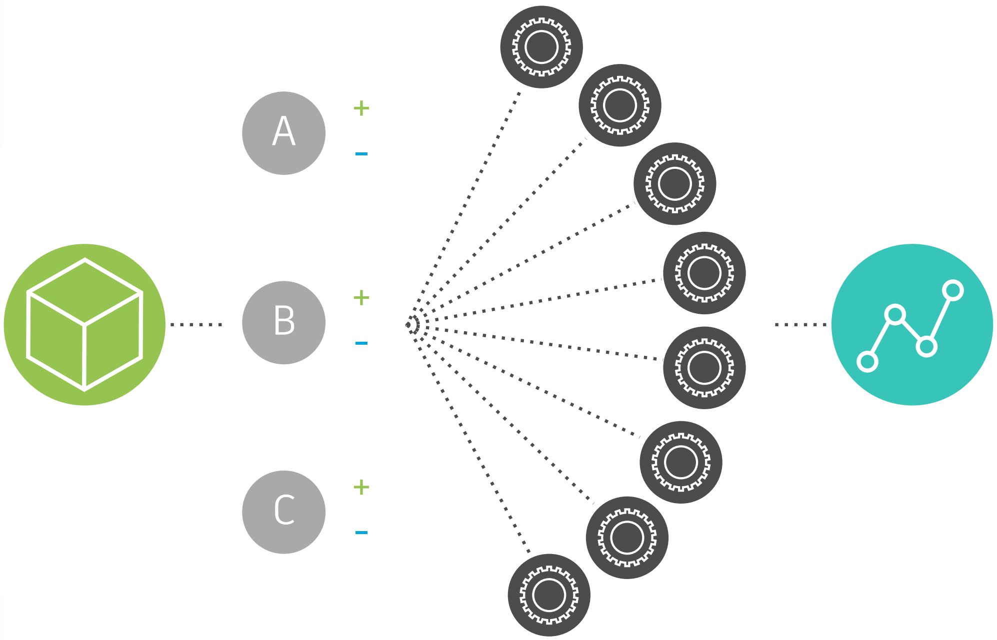


Figure 5b: An example of a typical parametric optimization workflow.

THREE APPROACHES TO OPTIMIZATION

Picking the right path

3. Design-of-Experiments (DOE)

Design-of-Experiments focuses primarily on process variables, automatically running a relatively large, predefined set of analyses in parallel to determine which variable adjustments will have the greatest impact on your criteria of choice, whether it is cycle time, part quality, or another metric.

1. Create baseline part and mold geometry
2. Identify process variables to investigate
3. Establish evaluation criteria
4. Setup and batch run DOE analyses
5. Interpret results to understand effects of variables on the quality criteria
6. Identify and document the best combination of process settings

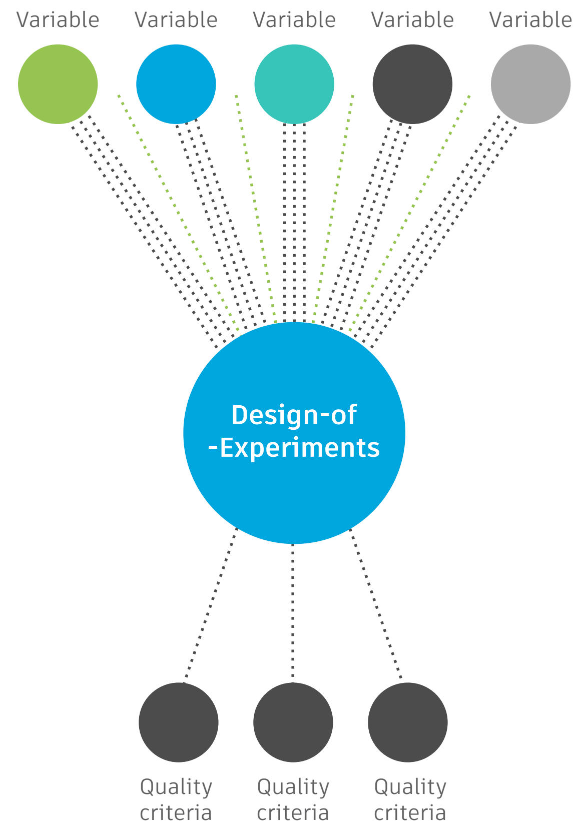


Figure 5c: An example of a typical DOE workflow.

DESIGN ITERATION

Design iteration is the most basic way to achieve optimization and the method with which most mold engineers will already be familiar.

DESIGN ITERATION

Wash, rinse, repeat

The workflow for design iteration is highly manual. In other words, the mold engineer needs to choose a geometric variable or process setting to adjust, make the modification within the simulation software, run the simulation, and compare the results to the previous iteration. Over time, this helps you converge on the best set of variables for your project.

The benefit of an iterative approach is that you can see the impact of each individual adjustment on the design. The downside is that it is much slower than the other two options. However, there are two points to keep in mind.

First, many simulation software tools include features that accelerate the setup process, allowing you to repurpose settings instead of starting every iteration from scratch. Second, design iteration is the only way to optimize certain variables (such as non-scalable aspects of the geometry) that are not appropriate for parametric optimization or Design-of-Experiments.

While iteration may be more time-consuming than an automated method, it also provides a great deal of practical experience in understanding the relationships between variables and outcomes. This experience will help you streamline your work in future projects.

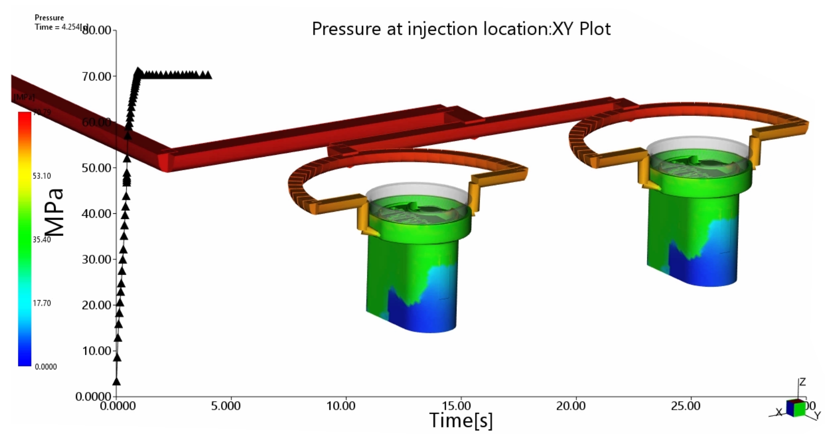


Figure 6: Using simulation software can help streamline the design iteration process.

PARAMETRIC OPTIMIZATION

Parametric study is a form of optimization that enables mold engineers to investigate the impact of changing one or more geometric variables.

PARAMETRIC OPTIMIZATION

Focus within a framework

Parametric optimization offers an automated way to examine changes to the geometry of the part or the mold in order to understand the impact each change has on cycle time.

Instead of manually adjusting the design for each variable (as with design iteration) mold engineers can automate the analysis by first defining a range of values to investigate for the parameter in question, whether it is wall thickness, cooling channel diameter, cooling channel placement, gate sizes, or other factors.

Each analysis represents one possible combination of the selected parameter values. For example, if three values of wall thickness and five values of cooling channel diameter are selected, the simulation software will run a total of 15 analyses.

One note of caution: be careful not to set up the parametric study to investigate too many variables at the same time, as this can compromise both analysis time and computing resources.

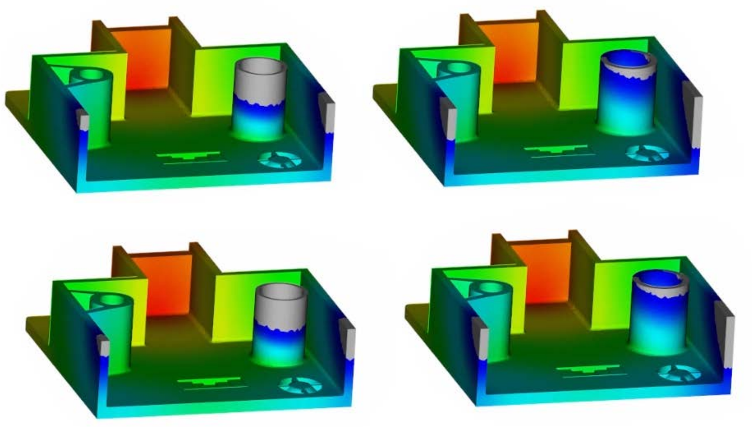


Figure 7: Simulation software helps visualize various combinations of parametric values.

PARAMETRIC OPTIMIZATION

Parametric workflow

The specific steps may vary from application to application, but the workflow for a parametric optimization typically follows these steps:

1. Import and mesh a CAD model.
2. Specify the molding process, analysis sequence, material, injection location, and processing conditions.
3. Initiate a parametric study.
4. Select the variables to investigate.
5. Assign values to each variable.
6. Select the comparison criteria. Options will depend on the molding process, mesh type, analysis sequence, and material.
7. Run the analysis.

Remember, the analysis will run every possible combination of the selected variables. For this reason, it is a good idea to select only those parameters that are likely to have a significant impact on cycle time and avoid wasting time on iterations that are not likely to produce usable results.

Select Studies	Study No.	Status	GEOMETRY MOD #1 Filter	GEOMETRY MOD #2 Filter	GEOMETRY MOD #3 Filter	INJECTION PRESSURE Filter	VOL SHRINKAGE Filter	DEFLECTION Filter	DEFLECTION Filter
☑	1		-0.25	-0.25	0	25.44	7.38	0.445	0.45
☑	2		-0.25	-0.25	0.5	23.45	7.45	0.456	0.445
☑	3		-0.25	0	0.5	20.54	7.43	0.45	0.456
☑	4		0	0.5	-0.25	21.48	7.38	0.443	0.444
☐	5		0	0	0	20.34	7.84	0.444	0.475
☐	6		-0.25	0	0.5	23.45	7.45	0.456	0.445
☐	7		0.5	0	0.5	20.51	7.43	0.41	0.426

Figure 8: An example of how to compare parametric results within mold simulation software.

DESIGN-OF-EXPERIMENTS

This sophisticated optimization method runs a carefully selected set of simulations to find process settings that willachieve your most important goals.

DESIGN-OF-EXPERIMENTS

The science of experimentation

Design-of-Experiments (DOE) is a statistical tool that enables mold engineers to see how changing a processing variable affects the quality of the part. It can also help you understand which processing conditions have the greatest impact on a given quality indicator.

DOE analyses search for optimal processing conditions by automatically running a series of analyses while varying the values for selected processing conditions, such as:

- Mold/melt temperature
- Injection/packing time
- Thickness multiplier
- Injection/packing profile multiplier

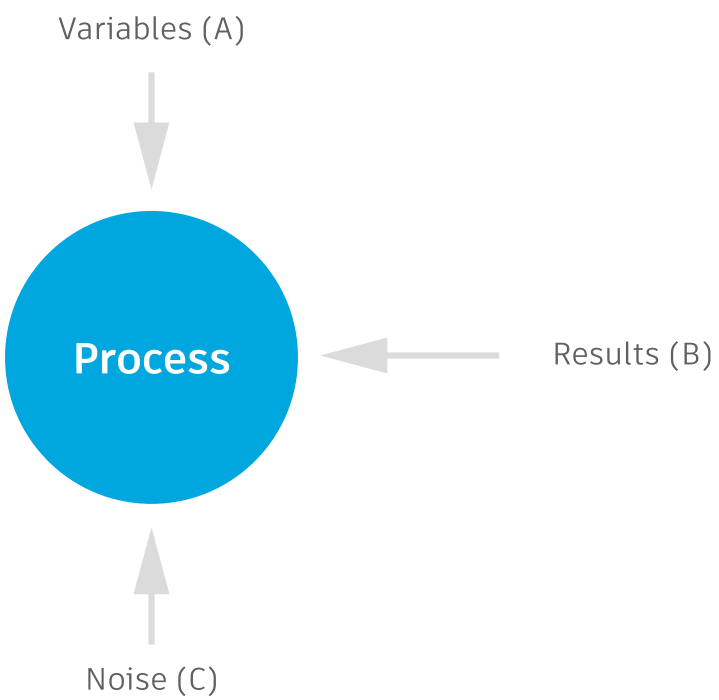


Figure 9: DOE is a statistical process used to understand the sensitivity and interactions among variables and results.

DESIGN-OF-EXPERIMENTS

The science of experimentation

This is done to optimize a wide range of (single-point) quality indicators, such as:

- Flow front temperature
- Shear stress
- Injection pressure
- Clamp force
- Volumetric shrinkage
- Sink mark depth
- Part weight

Cycle time

While a DOE analysis can be run at any time during the design phase, the ideal time to run it is after the material and gate location have been selected and an initial analysis has been performed.

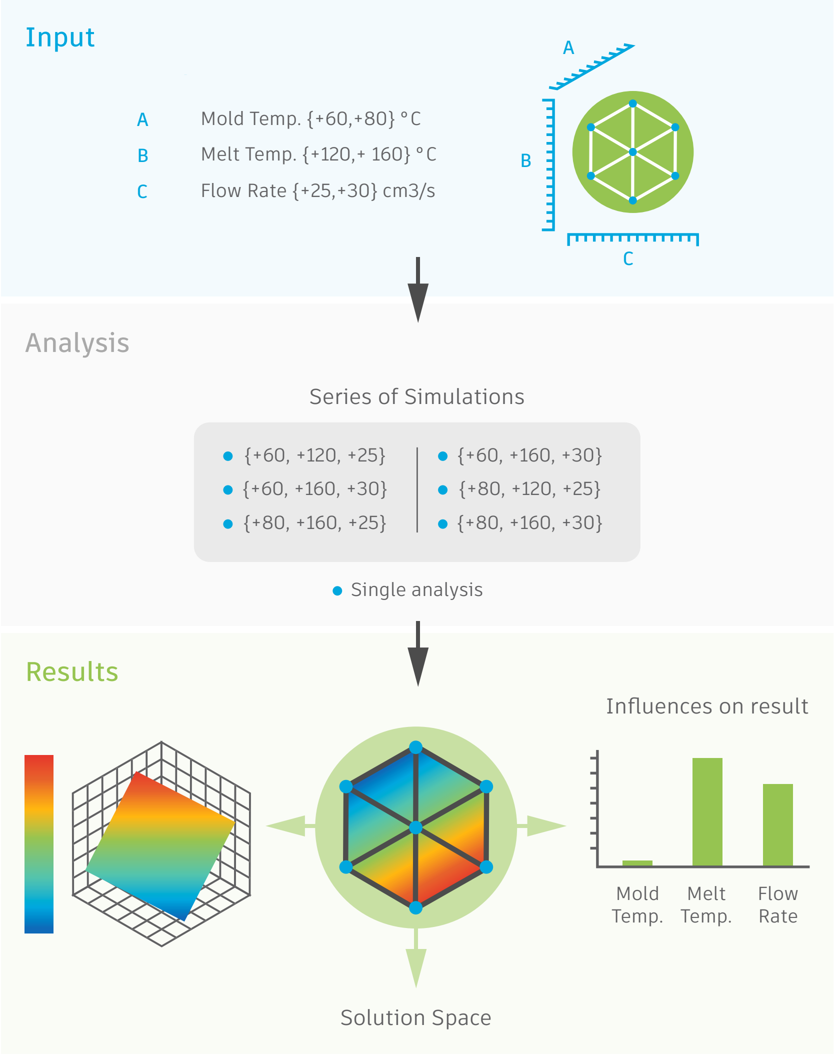


Figure 10. An example of DOE workflow applied to mold temperature, melt temperature, and flow rate.

DESIGN-OF-EXPERIMENTS

Advantages of DOE

The most important advantage of DOE is that it typically generates more high-quality information than conventional trial-and-error experimentation. More so than other methods of optimization, DOE can help mold engineers understand how sensitive the tool and part design will be to variation in process parameters, allowing you to recommend changes in the part or tool design to make the molding more stable.

Other benefits of DOE include:

- Multiple point solutions. DOE analysis provides a solution as well as information about the space around that solution. In other words, it gives engineers enough information to improve the design of the part or change an input parameter to improve the quality of the part, depending on the specific needs of the project.
- Time to solution. DOE analysis requires less manual input from engineers. While setup may take longer than other methods, results can be generated more quickly. Die trials can be shortened when mold engineers already know which inputs affect part quality and which do not.
- Improved quality. DOE analyses can present solutions that mold engineers may not have considered otherwise. It may also help identify search directions that can improve part quality.
- Trusted approach. DOE analyses are robust with a long history in engineering. Mold engineers typically have training in DOE and already understand its limitations. As an approved engineering tool, DOE should not meet with any resistance prior to implementation.
- Knowledge expansion. DOE helps engineers gain greater insight into the relationships between physical inputs and physical outputs in an intuitive way, in real time.

DESIGN-OF-EXPERIMENTS

DOE workflow

Because DOE is such a sophisticated optimization technique, the specific steps will vary depending on the simulation software. Overall, there are three phases to complete in the workflow:

1. Determine independent variables

The independent or "input" variables are those values that can change. The values for each are typically assigned in a range around a middle value. This range can be narrowed or widened.

- Processing conditions. These variables are associated with the actual production of the part, such as filling control, cooling time, curing temperature, injection time, and pack/holding control.

- Boundary conditions. These variables define how to model heat transfer conditions between the mold and the material. They include coolant inlet and associated variables; valve gate timing and associated variables; the mold surface temperature profile controller; the hot gate pressure controller; and the gas inlet controller and associated variables.

- Geometry variables. Geometry includes any variable associated with the physical design of the part, such as wall thickness.

DOE workflow

2. Select criteria to measure.

In DOE, quality criteria are the indicators that define part quality, such as sink mark depth, part mass or cooling time. Quality indicators are typically related to filling and packing, cooling, and shrinkage and warpage. Choosing a quality criterion may also involve selecting other contextual factors:

- Weighting. Quality indicators often can be weighted. If your objective is to reduce cycle time, for example, the cooling time variable can be ranked as most important.
- Goal. This refers to the objective of the DOE analysis, such as "to minimize sink mark depth."
- Calculate. Choosing the source of the values used in the DOE analysis will significantly affect the results. For example, if you select "maximum" for sink marks, then the deepest sink mark identified in the results will be optimized during the analysis.

3. Run the analysis.

At this point, the simulation software has all of the information it needs to prepare the required number of simulations and process them. When they are complete, mold engineers can see the optimal settings based on your pre-defined quality criteria. The response surface plot will typically be a 3D representation or "surface graph" that shows the effect of two variables on a quality criterion while keeping all other variables constant.

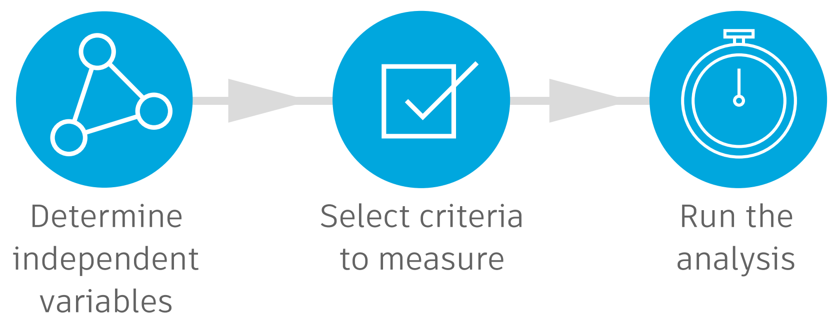


Figure 11: Following the three fundamental steps for DOE should provide ample opportunity to interpret results and optimize results.

CONCLUSION

Stick to the plan

No matter what method you prefer, the goal of optimization is to find the best possible solution to the design challenge at hand. It is imperative to have a clear objective and to use a systematic, scientific approach. This helps avoid the risk of reacting to individual results one by one, without a plan, and eventually settling for a suboptimal design when time runs out.

Automation and cloud computing provide distinct advantages because they allow mold engineers to simulate a wider variety of geometric and process settings simultaneously in less time. Examining more of the design space sets the stage for convergence on the values for each variable that will deliver the lowest cycle time while adhering to specifications and maintaining part quality.

Get Started

To learn how simulation software can help you optimize parts and processes more effectively, visit our Solution Center.

SOLUTION CENTER >

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