PROTOTYPE TO PRODUCTION

MANUFACTURING ACCELERATED

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PROTOLABS
Manufacturing. Accelerated.

3D PRINTING
CNC MACHINING
INJECTION MOULDING

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RESOURCES

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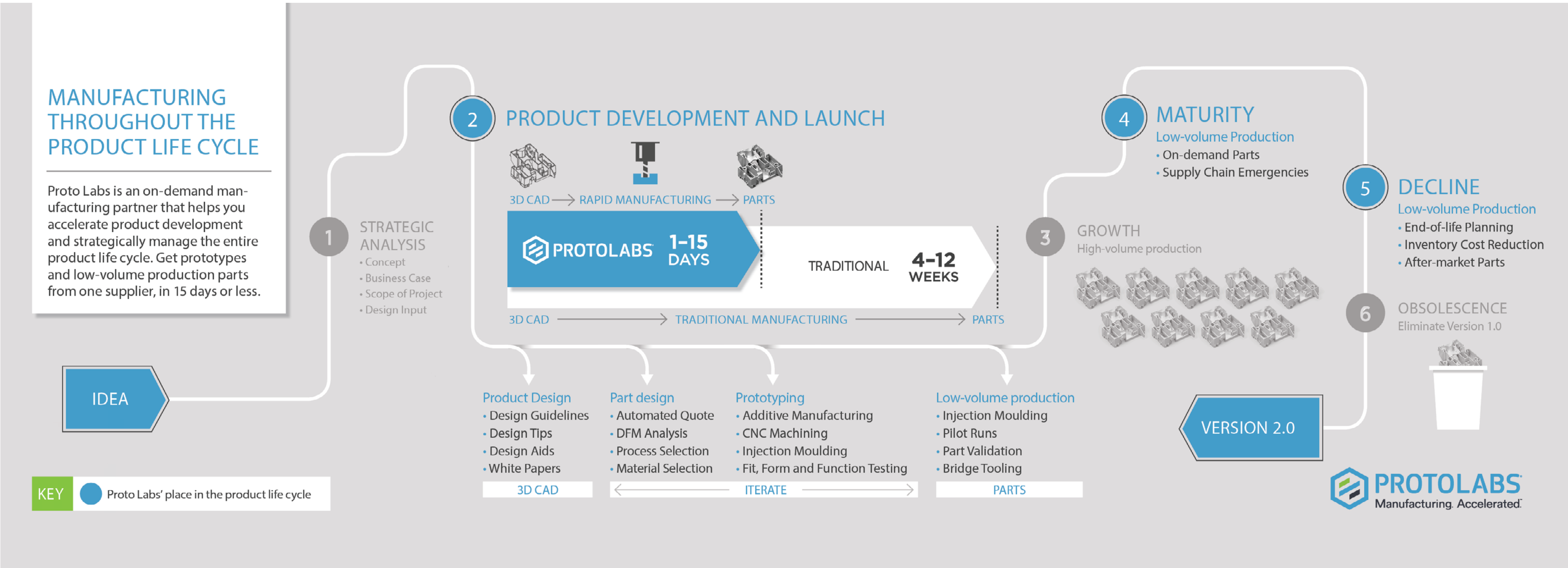
In the drive to accelerate new product development and time to market, the pressure to validate a design can be intense. With a prototype of a product or component, designers' finally move designs from the screen to physical objects that can be handled. Does it fit? Will it function as intended? Can a 3D printed part be manufactured by injection moulding? And—in the case of prototype products, rather than parts—what might potential customers think of it?

But the pressure to prototype features or design elements, focus on the resulting end product can be lost. Aim for a prototype, and that's what you'll get—a prototype, and perhaps one of several as the design is refined.

Increasingly, smart manufacturers—and their design teams—are looking ahead, past the prototyping phase of the product design process, and are thinking in terms of the end product and its required performance characteristics.

The objective: prototypes that are more than just physical representations of a design, but which instead smooth the way into final production, as well as providing valuable information on product performance and conformance.



In product development, parts or products generally move through three phases of evolution: first, prototyping; second, low-volume production; then third—and final—serial production.

Prototyping is about crystallising a proven, working design. A prototype can be one of several (or many) such iterations, or just a final one-off physical validation of an on-screen design before design sign-off. On the other hand, low-volume production is less about the product itself, and more about its market or production process: a phase of low-volume production can help to refine a manufacturing process, or alternatively get test products or launch products to market in order to gain and validate customer perceptions. Finally, the precise volumes that are associated with serial production will depend on the product itself, and its market, and will typically range from thousands each year, to millions each year.

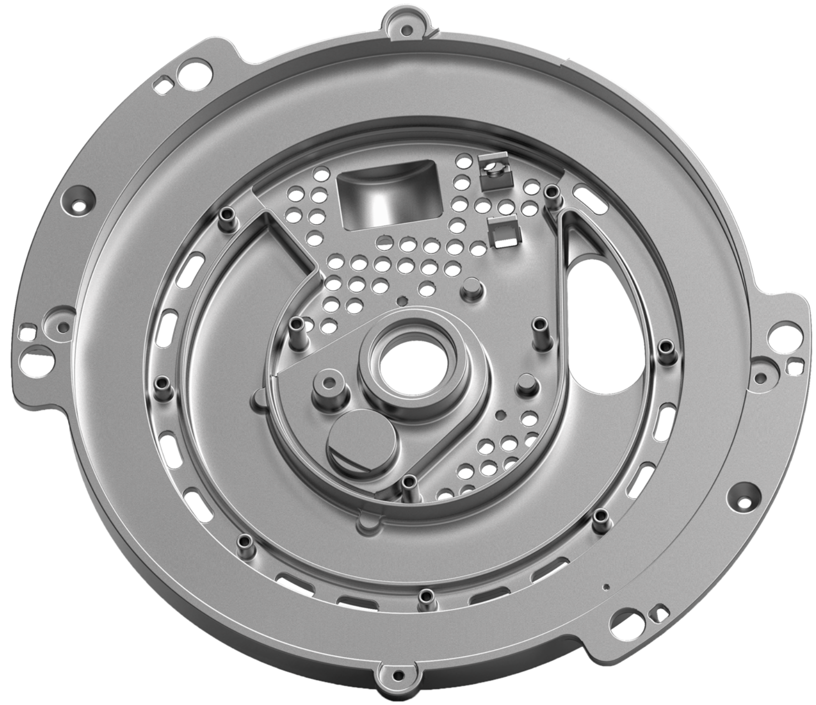
In each case, the goal at each stage is to move smoothly from each phase of development to the next, refining the product and its manufacturability. Overall, the objective is to minimise the total time and cost of the overall process, bringing a product from initial concept to serial production smoothly and efficiently, and as quickly and cost-effectively as possible.

In some industries bringing a product to market involves extensive compliance testing, often involving third-party certification. Aerospace and defence product development, for instance, calls for such compliance, and no manufacturer will want to finalise a product design and get ready for serial production, only to discover that the product in question does not meet its design requirements in terms of durability, usage cycles, or some other testable attribute. Making use of the prototyping stage to carry out such testing—a process known as pre-compliance testing—is therefore prudent. In such circumstances, it makes excellent sense for a designer to seek guidance from the prototyping provider in order to use a prototyping material that will yield meaningful information on attributes such as strength, flexibility and durability.

Finally, as well as these development and testing stages of bring a product to market, a manufacturer may wish the prototyping and development process of a product to take into account a number of broader business considerations.

Decisions about packaging, for instance, can impact packaging cost, vulnerability to damage during shipment, and the cubic utilisation of both primary and secondary packaging. Ultimately, of course, cubic utilisation will affect vehicle and container requirements, as well as shipping cost. It can be prudent to, wherever possible, use product prototypes in order to inform packaging decisions as early as is practicable.

Similarly, a business may have sustainability and branding objectives in addition to those impacted by packaging and shipping utilisation. A decision to use a particular means of packaging, for instance, may again impact damage statistics, or product aesthetics during a long shelf-life. An objective of using high levels of reclaimed plastic may not prove practical when injection moulding a specific part. And sourcing both prototypes and production parts over long distances will impact a business's carbon footprint, as well as drive costs higher.



Quality, reliability, and business resilience are other important considerations. These are generally trade-offs: the cheapest prototyping provider will not usually be the fastest, or produce the highest-quality prototypes, for instance. Maintaining a close business relationship with a prototyping provider is becoming a strategic consideration for many businesses; value is placed on sourcing a recommended manufacturer as an outsource partner with the ability to satisfy prototype needs, plus low- and medium-volume product requirements. These suppliers provide the support that fully understands the need for DFM (design for manufacture) and are key to smoothing the way.

In short, successfully bringing a new product to market can call for a multi-faceted approach to design and development, embracing a wide range of issues, priorities, and trade-offs. In this paper we look at how an intelligent approach to prototyping strategy at each phase of the development process can help with this. The objective: an approach to prototyping that shortens overall development time, and brings to market a better product with a better performance, and at a lower overall development cost.

Prototyping considerations for a design's early stages

The early stages of the project development process include concept development, initial design and product validation, and some product testing in terms of aesthetic appeal or functionality.

During these initial stages, the design function aims to combine the Voice of the Customer (VOC) requirements; the Voice of the Process (VOP), which specifies current manufacturing and sourcing capabilities, together with any known investment requirements; and the Voice of the Business (VOB), which details the business's demands and hurdles in terms of return on investment, sales, marketing and operations

Prototypes are a significant investment for R&D teams, and where possible, manufacturers are increasingly turning to rapid prototyping techniques to shorten development times and reduce risk, using technologies such as:

- 3D printing
- MultiJet Fusion (MJF)
- Selective Laser Sintering (SLS).
- Stereolithography (SL)
- Direct Metal Laser Sintering (DMLS)
- CNC machining
- Injection moulding

Prototype quantities can range from as few as one per prototype iteration, to as many as hundreds or even thousands, depending on the product and the project's requirements. That said, the usual range is between one and five for initial concept prototyping using CNC machining or 3D printing, to hundreds when using rapid injection moulding. However, we should be mindful not to restrict or categorise these technologies to prototyping only. Indeed, where only a few production parts or components are required, 3D printing, CNC machining or injection moulding are commonly used to manufacture production-ready parts.

Each manufacturing technology produces compromises. Speed, cost and the level of useful information that a prototype can provide, are all considered at the initiate stage of the project. Prototypes are often manufactured using different materials and processes than would be used during actual production (3D printed plastics for example), with parts produced largely in order to provide information about fit, function, and aesthetics. For some projects, particularly in later prototyping iterations, manufacturers require pre-production prototypes that are representative of parts used in the final product, made from the same material and manufacturing process.

CONCEPT SCREENING				
ELECTION CRITERI	CONCEPTS			
	1	2	3	4
	Reference design	Concept A	Concept B	Concept C
Ease of operation	0	0	0	0
Versatile	0	+	+	-
Safety	0	0	+	+
Ergonomics	0	0	+	+
Durable	0	0	-	-
Low cost	0	+	0	0
Easy to develop	0	+	0	-
Sum of +'s	0	3	3	2
Sum of 0's	7	4	3	2
Sum of -'s	0	0	1	3
Net Score	0	3	2	-1
Rank	3	1	2	4
Continue	Yes	Combine	Combine	No

Prototyping considerations for the move to low-volume production

Once prototypes have been validated in terms of fit, form, function, and aesthetics, development can move to low-volume production , developing on-demand supply chains or before moving on to serial production. This stage of manufacturing consists of batches of parts that range from 50 to several hundred of several thousands, scheduled to match production needs, providing parts that are delivered to meet fluctuating demand. Furthermore, for certain projects, low-volume production can be the actual, and final, method of production.

The project development strategy will dictate how quickly the manufacturer will move to low-volume production, and how long this stage of production is likely to last. Such a strategy will also include an understanding of the scale of such production—in tooling and production terms, batches of 50 are one thing, batches of several thousand quite another.

The principal implication at this stage is to have parts produced that provide useful insights in terms of fit, form, and function, but which are also optimised for manufacturability. Again, it is one thing to have a physical prototype that confirms that a part or product will perform the intended task, and quite another to have a physical prototype where the means of producing it have been optimised for manufacturability.

For low-volume production, a primary aim of optimised manufacturability is to tweak prototype designs so that moulding tooling can be manufactured more quickly, or more cheaply—or both, in conjunction. In addition to these tooling considerations, a manufacturer will usually want to achieve optimised mouldability, as well. Potentially, for instance, a small change to a mould's draft angle can deliver significant improvements in part ejection and therefore both surface finish and strike rate.

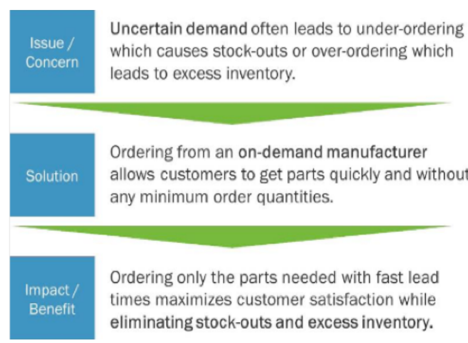
How to achieve this optimisation? In an ideal world, a manufacturer's choice of prototyping and low-volume production provider will have taken this requirement into account, and selected a provider that can offer both insights delivered through human-based application engineering skills, as well as automated tools that can cost-effectively provide an initial rough-cut optimisation analysis automatically, without human intervention.

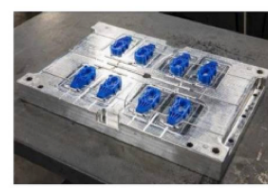
Indeed, in many cases, it can prove possible for automated design optimisation tools to completely deliver a degree of optimisation that is perfectly adequate for low-volume production. Usefully, when such tools are delivered through high-powered compute clusters, this optimisation can be achieved at minimal delay to the part production process—which is usually important, as achieving a rapid time to market remains a primary objective.

At Protolabs, for instance, when designers upload a 3D CAD model to the website, a quote is returned within a few hours which highlights detailed sections of the model that are in need of draft angles, and which even offers suggested changes to improve the draft on those sections.

Rapid injection moulding works by injecting thermoplastic resins into a mould, just as in production injection moulding. What makes the process "rapid" is the technology used to produce the mould, which is often made from aluminium instead of the traditional steel used in production moulds.

Moulded parts are strong and can have excellent finishes. It is also the industry standard production process for plastic parts, so there are inherent advantages to prototyping in the same process if the situation allows. Almost any engineering-grade resin can be used, so the designer is not constrained by the material limitations of the prototyping process.





With multi-cavity tools, even high quantity runs are possible if there is concern for sudden spikes in demand

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Typically, an intelligent prototyping strategy will reflect on both the rate at which the project is expected to ramp up to low-volume production phase, and the time—or rather, total output—that this phase of production is envisaged to take to complete.

Often, the production rate takes on greater significance during low-volume production, and as aluminium tooling does not retain heat to the same extent as steel tooling, mould tools are both quicker to reach temperature, and allow faster cooling prior to ejection or release, potentially leading to a higher output rate.

And given that well made low-volume or 'bridge' aluminium tooling can last for thousands of cycles—with some tools capable of producing over 200,000 parts—it definitely makes sense for manufacturers to view such tooling as a viable alternative to more expensive steel tooling. Steel tooling may be required eventually, but there is little point in discarding perfectly serviceable aluminium tooling, if aluminium can do the job well indefinitely.

Prototyping considerations for the move to serial production

The move to serial production raises fresh issues for an intelligent prototyping strategy to consider. One key consideration, for instance, revolves around how quickly a given part or product will transition to serial production—in the case of parts or products that are in effect simply a new iteration of an existing proven design or product, the time spent in the low-volume phase of product evolution could be minimal or a way to adopt on-demand production allowing continual product development throughout the product lifecycle.

In such circumstances, it is important for prototyping to quickly prove serial production practicality, as the product or part will spend less time going through the low-volume validation process than it did during its first production run. So while early-stage prototypes may make use of rapid prototyping techniques such as MJF, DMLS, SL or SLS, it will make sense for later-stage prototypes to be manufactured using CNC machining or injection moulding that is consistent with the intended serial production technology.

And as with low-volume production, it makes sense to use a prototyping provider with strong capabilities—both automated and human—in application engineering. With serial production, the focus moves from simply producing a part or product to actively searching for design optimisation that can yield returns over a long production run. With such optimisation, manufacturers can achieve significant improvements in yield, material use, strike rate, and surface finish, fine-tuning a design that may have worked perfectly satisfactorily in low-volume production, but which still offered the possibility of longer-term improvements.

Resin	MM
ABS	1.1 - 3.5
Acetal	0.8 - 3
Acrylic	0.6 - 3.8
Liquid crystal polymer	0.8 - 3
Long-fibre reinforced plastics	1.9 - 25.4
Nylon	0.8 - 2.9
Polycarbonate	1 - 3.1
Polyester	0.6 - 3.1
Polyethylene	0.8 - 5
Polyphenylene sulfide	0.5 - 4.5
Polypropylene	0.6 - 3.8
Polystyrene	0.9 - 3.8
Polyurethane	2 - 19

Light-weighting initiatives, for instance, not only reduce weight—a valuable attribute in many applications—but can also reduce material input and therefore cost: a general rule of thumb for wall thickness in the case of thermoplastic parts and products is somewhere between 1 to 3.5 mm (for ABS), applied consistently across the entire part. In other words, thinner walls do not simply reduce cost though reduced material input, but they also reduce cost through improved manufacturability.

Recommended wall thickness by resin.
For example, very thick cross sections increase both the likelihood of cosmetic defects such as sink, and the probability of yield losses through warp and sink during cooling. Paying careful attention to tooling radii, especially in the case of aluminium tooling, is also a useful way of improving yield over a long run of production.

In serial production, too, there may be opportunities to take advantage of multi-cavity or family moulds in order to mould multiple parts in a single injection cycle. Multi cavity moulds involve more than one cavity cut into the mould to allow for multiple, identical parts to be formed in a single shot; family moulds involve more than one cavity cut into the mould to allow for multiple, different parts to be formed in one shot. If this looks to be a viable option, then engineering experts at Protolabs generally recommend first proving the design on a single cavity mould, before committing to the additional expense and complexity of a multi cavity or family mould.

Putting it all together: the big picture
The pressure to bring new products to market, as quickly as possible, can be intense. Naturally, then, the pressure to produce prototypes can be just as insistent.

But taking a step back, and thinking first about the end product—and its production and testing requirements—can pay dividends both in terms of the overall timescale, as well as the overall cost. Usually, too, there are benefits in terms of yield, product cost, and product performance.

Broaden that focus a little more, and include a consideration of such things as packaging, and the benefit stream is even more compelling.

To be sure, an intelligent prototyping strategy may add a little time in the early stages of the development process. But this is an investment, not a cost. An investment, in short, that leads to a better product, with a better performance, and one which has been derived at a lower cost, in a shorter overall timescale.

For more information

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