Choosing the Right Rapid Prototype Source for Your Product Development Program

Phillips Plastics Corporation
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Introduction
Being able to create prototype injection molded components and assemblies quickly gives product developers a critical competitive edge. It is essential to have clear and complete understanding of all aspects of the rapid prototyping process—industry standard terminologies, methods used, their comparative advantages and disadvantages, and the differences in supplier capabilities—in order to meet product development milestones. In addition, having a clear vision of how you want to produce the product in final form can help you bring new products to market with optimal timing and cost efficiencies.

This document examines general industry standards and methods in rapid prototyping, compares differences between technologies, and explores overall strategic project management considerations necessary for successful new product prototyping under tight time constraints.

Overview of Terminology 
& Processes for Prototype Creation
Processes for creating rapid prototypes take many forms. Each process has its advantages, disadvantages, and unique characteristics.

Each of the processes discussed here utilizes 3D CAD files as the input, and requires varying levels of engineering manipulation to create the prototype.

Additive Processes
The available technology for additive creation of prototype models is rapidly changing, as new materials and processes are introduced to the market. Below is an overview of the most widely available additive processes.

Stereolithography (SLA)
Stereolithography is an additive fabrication process that utilizes a laser to cure thin layers in a vat of liquid UV-sensitive photopolymer. Model resolution can be modified by changing laser “spot size” and layer thickness. Smaller spot size and layer thickness increase resolution, and also increase build time and cost.

SLA models can be post-processed for varying levels of finish. The most basic finish, “strip and ship,” removes supports and cleans the parts. Other options include a functional finish, in which the parts are sanded and bead-
blasted, making them suitable for engineering review. SLA models may also be finished and decorated to provide an accurate visual representation of the part.

**Pros:** Capable of producing complex patterns and models suitable for use as masters for other prototyping methods. Parts have excellent surface finish without secondary operations. Pricing is very competitive.

**Cons:** Functional testing is usually not possible on SLA parts, as they tend to be weaker than parts made of engineering resins. The UV curing aspect of the process makes parts susceptible to degradation from sunlight exposure. Despite being capable of generating complex parts, the process gives no indications as to ultimate manufacturability of the design.

**Fused Deposition Modeling (FDM)**

Like SLA, fused deposition modeling is an additive process used to produce highly accurate and durable prototype parts from CAD files. FDM creates models layer by layer using a thermoplastic extrusion process.

While the as-built surface finish of FDM models is generally rougher than that of models produced using SLA, the end product is typically more robust. FDM is considered ideal for applications where functional prototypes do not require high-quality visual surfaces.

FDM is also a suitable process for building assembly, testing, and inspection fixtures that would otherwise be difficult or impossible to machine.

**Pros:** Parts can be strong enough to allow functional testing. Parts with complex geometries are possible.

**Cons:** Process is slower than SLA and SLS, and parts have a comparatively poor surface finish. Does not approximate manufacturing. Part orientation is critical for any snap features.

**Selective Laser Sintering (SLS)**

In selective laser sintering, models are created by adhering layers of laser-cured resin powder to a moveable platform using a tracing laser. The SLS process can use a variety of polymer powders that can approximate the performance of thermoplastics after sintering. SLS parts can often be machined following the process, and features such as living hinges can be incorporated into the parts. SLS models may also be finished and decorated to provide an accurate visual representation of the part.

Think of prototyping in the overall context of bringing a new product to market, rather than as a standalone process. A prototype developer that can offer engineering expertise in all aspects of the process—including overall program management—will improve your odds of bringing out the product on-time and on-budget.
Pros: Process can make complex parts that are generally more durable and accurate than SLA parts.
Cons: Powder-based process produces parts with grainy texture; poor mechanical properties make parts usually unsuitable for functional testing. Limited number of resins available in powder form. Does not approximate manufacturing.

PolyJet
The PolyJet process utilizes jetting heads and UV curing bulbs located adjacent to the heads as each layer of material is applied. PolyJet is capable of applying multiple colors and durometers of material in the same build and provides an additive representation of multi-material parts.

Performance properties of the UV cure photopolymer are similar to ABS or TPE.

Pros: Process produces parts with excellent surface finishes and complex geometries. It can also reproduce fine detail better than most additive processes.
Cons: Low durometer materials have poorer strength properties. Not useful for evaluating manufacturability.

Direct Metal Laser Sintering (DMLS)
Direct metal laser sintering uses laser-generated heat to sinter thin layers of metal powders to create finished products. Material options include steel, stainless steel, cobalt chromium, and titanium.

Pros: Quickly produce near net, or in some cases, net shape metal parts. Near net shape parts can be machined conventionally to produce very accurate complex parts.
Cons: Limited materials. Rough “as-built” surface finish. Difficult to clean up or polish surfaces unless secondary machining is done. Should evaluate time and cost to determine if DMLS is cost effective when compared to 100% machining from billet.

Direct Digital Manufacturing (DDM)
Applying additive processes to low volume production is often referred to as direct digital manufacturing. This enables low volume production without tooling investment, or the constraints on design for higher volume manufacture via tooling. (Includes all of the additive processes covered in this document.)

FDM prototyping can produce parts that are robust enough for assembly and testing. It is a good option in cases where parts would be virtually impossible to machine.

Prototype models that look and function like the finished product may require integrating multiple materials and processes.
Subtractive and Casting Processes

**CNC Machining**
CNC machining will produce finished parts from a variety of materials, including plastic, aluminum, magnesium, titanium, and steel, by cutting parts from blocks of the desired material. CNC machining is generally the most accurate prototyping process but has greater design constraints than additive processes. CNC also has higher cost and lead time than additive processes.

**Pros:** Produces strong parts with good surface finish. Suitable for engineering evaluation and testing. Models can be machined out of plastic, aluminum, magnesium, or most other metals.

**Cons:** Part geometries can be limited due to the nature of CNC machining. Process can be expensive because programmers and machinists are needed to produce the parts. Parts may differ from volume manufacturing due to limitations of the machining process.

**Casting**
Urethane casting is a process that is sometimes utilized for creating multiple models using a single master model as a pattern. The master model, typically built using the SLA or Polyjet process, is finished and textured to simulate the final product. Silicone rubber is poured over the part, and when cured, the master model is removed, leaving a core and cavity capable of producing up to 25 copies of the original. The mold is then injected with a liquid urethane thermoset resin that can be custom tinted, resulting in parts that are production-like in appearance, and can be used for fit and function evaluation, as well as some limited testing. In some cases machined acetal or ABS molds are used to create multiple urethane elastomer parts in a wide range of durometers.

**Pros:** Allows you to make multiple copies of models very quickly, while incorporating most custom colors and textures. Wide range of mechanical properties and durometers. Flexible silicone rubber molds allow you to mold some features that can’t be molded conventionally without special tooling, keeping costs down. Molded in inserts and overmolds are possible.

**Cons:** Thermoset urethanes are not representative of injection molded thermoplastics. Limited functional testing. Variables in the creation and finishing of the master model, the construction of the silicone mold, and the de-molding and finishing of the castings can affect accuracy.

By choosing the right process, it is possible to generate prototype models that incorporate complex geometries and multiple materials. Fine-tuning the design at the CAD stage—with knowledgeable input from the prototype maker—is vital to a successful outcome.
Rapid Injection Molding Processes

CNC Machined Rapid Tooling
The fastest lead time and lowest cost injection mold tooling is created by CNC machining the part geometry into aluminum or soft steel (such as P-20) mold inserts. CNC machining may require modifications to the design to allow CNC machining of certain features, such as radii and draft angles. Undercuts also require special consideration with this tooling approach.

Pros: Process provides a good predictor of manufacturability during production. Parts can be molded from a wide range of engineering resins with excellent surface finish. Can also be used for metal injection molding (MIM).

Cons: Tooling costs can make the process appear to be more expensive than others on first examination, but cost per finished piece is usually significantly lower than additive processes or CNC machining. CNC machined tooling has geometry limitations, many of which can be overcome with conventional rapid tooling.

Conventional Rapid Tooling
Conventional mold building techniques can be applied to rapid tooling to allow more advanced geometry than allowed by CNC machined rapid tooling, while still delivering shorter lead times than production tooling. EDM (electronic discharge machining) is used to better match the tooling with the design. Rapid tooling also allows the use of more advanced, durable materials such as hardened steel. Undercuts are usually formed with automated slides, and advanced gating techniques may be used. An advanced conventional rapid tooling approach provides a low cavitation rapid tool built to similar standards that may be applied to higher cavitation, higher volume production tools later in the development process.

Pros: More complex part geometries. Parts of production-intent quality can be produced in small to mid quantities. Tooling is more production representative than CNC machined rapid tooling. Can be used for metal prototyping, such as MIM or die casting.

Cons: Requires a larger financial and longer time commitment than other rapid processes. Modifications are possible, but more costly than for other methods.

Continued on page 8...
### How Rapid Prototyping Technologies Compare

#### Additive Processes

<table>
<thead>
<tr>
<th></th>
<th>SLA</th>
<th>SLS</th>
<th>FDM</th>
<th>PolyJet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials Available</strong></td>
<td>UV cured photopolymer (similar to ABS or PP)</td>
<td>Laser cured Nylon® Plastics: ABS, PC, ABS/PC, PPSF, ULTEM®</td>
<td>UV cured photopolymer (similar to ABS or TPE)</td>
<td></td>
</tr>
<tr>
<td><strong>Tensile Strength</strong></td>
<td>Fair</td>
<td>Poor</td>
<td>Fair</td>
<td>Fair</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Thin Walls</strong></td>
<td>Fair</td>
<td>Fair</td>
<td>Poor</td>
<td>Fair</td>
</tr>
<tr>
<td><strong>Tolerances</strong></td>
<td>Good</td>
<td>Fair</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Finishing</strong></td>
<td>Post-build finishing - show model</td>
<td>Post-build finishing - show model</td>
<td>Limited</td>
<td>Post-build finishing - show model</td>
</tr>
<tr>
<td><strong>Secondary Finish</strong></td>
<td>Painted Pad printed Plated</td>
<td>Painted Pad printed Plated</td>
<td>Painted Pad printed Plated</td>
<td>Painted Pad printed Plated</td>
</tr>
<tr>
<td><strong>Functional Samples</strong></td>
<td>No</td>
<td>No</td>
<td>Limited</td>
<td>No</td>
</tr>
<tr>
<td><strong>Proof of Design</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Process can be Applied to Metals</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Multi-Material Components</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Tooling Required</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Replicates Volume Production</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Typical Days to Produce</strong></td>
<td>1-3</td>
<td>1-3</td>
<td>1-3</td>
<td>1-3</td>
</tr>
<tr>
<td><strong>Cost per Part</strong></td>
<td>$$</td>
<td>$$$</td>
<td>$$$</td>
<td>$$$</td>
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</table>

#### Subtractive Processes

<table>
<thead>
<tr>
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<th>Injection Molding</th>
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<tr>
<td><strong>CNC Machining</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Urethane Casting</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rapid Tooling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Materials Available</strong></td>
<td>Many engineering grades</td>
<td>Many polyurethanes, varying hardnesses</td>
</tr>
<tr>
<td><strong>Tensile Strength</strong></td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>Excellent</td>
<td>Good</td>
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<tr>
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<td>Yes</td>
</tr>
<tr>
<td><strong>Replicates Volume Production</strong></td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Typical Days to Produce</strong></td>
<td>1-10</td>
<td>5-7</td>
</tr>
<tr>
<td><strong>Cost per Part</strong></td>
<td>$$$$$</td>
<td>$$$$$</td>
</tr>
</tbody>
</table>

These tables show comparative performance of different rapid prototyping technologies at a glance. As you can see, no one process is right for all applications. Careful process selection with ultimate production goals in mind will help ensure the best product development results.
Know Your Prototype Developer

While one’s initial impression may be that prototype developers are generic and that they provide a commodity service, the opposite is true. Put simply, no two prototype providers are alike.

Broad variations in end product quality exist between providers, even when using the same equipment and processes. In some cases, a design simply run through the system “as-received” can result in unusable prototypes being generated, especially if the wrong process is selected for the part geometry or intended use of the prototypes. When this occurs, any expected cost savings from use of a low-cost provider are not realized, and time to market is sacrificed. Virtually all of the additive processes, CNC equipment, and injection molding machines utilized for creation of your prototypes are readily available capital equipment, and these tools are only as effective as the user’s knowledge and experience will enable.

How you and the prototype provider do business together is also important. Timely prototype development requires a tight interface between the prototype shop and its cost estimating function. For example, some providers who purport to offer rapid cost quotations do not actually do so; the process becomes manual after your design file has been uploaded. You should receive a timely prototype cost quotation upon uploading the design file, and you should be able to pay easily using either an established vendor credit account or a credit card. Often, a blanket purchase order can be generated that can cover several projects.

The most effective prototype development resources are companies that regard themselves as their customers’ product development partners and take that responsibility throughout the process.

Prototype Provider Business Models

Some additive prototype firms are referred to as “service bureaus,” which accept the design files and builds using the process requested by the user. Care is usually taken to orient the part geometry for best appearance or mechanical performance. Service bureaus typically focus on between one and three additive processes.

Service bureaus will provide short lead times and competitive costs for additive processes. The procurement process is in most cases web-based, and payment via credit card may be available for ease of use.
This approach provides the user with prototypes for general evaluation (fit, limited testing, “show and tell” samples, etc.), but does little to prepare and learn for production.

Prototype “brokers” have also emerged in the past several years. These sources offer project management and procurement of a wide array of prototypes from a supply base, and may not actually own or operate any prototype equipment.

In the middle of the prototype spectrum are niche prototype providers who perform a single service or a small group of services in-house, and focus on prototyping as their primary business. Niche providers usually offer a mix of additive, subtractive, and rapid tooling prototype processes, and may also be “brokering” these services to expand offerings. Niche providers can alert you to design issues for their respective processes prior to generating prototypes, and the user can modify and re-submit their design for evaluation. The niche providers offer a larger tool box for the user to choose from, and are an excellent resource for OEMs that rely on in-house production. On the other hand, the niche provider may not offer the experience and early manufacturing involvement to prepare for a seamless transition to high volume manufacturing if the OEM relies on contract manufacturers.

Top-level providers are full-service engineering and manufacturing firms that perform most or all of the prototype development functions in-house, and outsource remaining needs to carefully selected partners. Firms that can offer full-service functions are rare, but they can be invaluable partners in bringing new products to market as quickly and cost effectively as possible. These developers evaluate your designs prior to building any models or tools, and have the engineering knowledge to optimize designs for higher volume production intent. In addition, these providers have many prototyping options at their disposal, and have the product development experience and systems to help you pick the right prototype process for the stage of your product development, as opposed to selling you the technology they offer.

**Picking the Right Process for Your Needs**

Choosing the right prototyping path for your product development needs is typically dictated by your product development phase, the number of pieces intended for annual production, product launch timing, and risk
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management. As a very general rule, 1,000 units per year is typically the “magic number” at which point the product justifies elevation to full production status rather than utilizing a prototype shop to meet production needs. Integrating the development process from design through prototyping and production is the most cost and time effective way of putting new products into the marketplace. To ensure the highest level of integration, there are two basic (yet critical) questions to evaluate for selection of the best prototyping path for your project:

What do you intend to do with the prototype parts?
Be sure to choose the right method for your intended purpose. Think ahead in the product development process and consider the long-term implications of the method you select. Your product development phase—concept development, design, design verification, validation, production ramp-up, or low-volume production—will dictate how you proceed. If you are unsure about any aspects of the process, the prototype provider should be able to answer your questions and guide you to workable solutions.

How closely do you want to replicate the final production process with your prototypes?
Do you simply need parts for evaluation, or do you need a prototype method that also allows learning in preparation for volume production? The expected production volumes influence the level of prototyping required to manage downstream risk. As product volumes increase, the production tooling methods change. Replicating your production tooling with a lower volume tool allows you to learn and prepare for higher volume manufacturing, or perhaps even using the prototype tooling as production “bridge tooling.”

A Quick Guide to Selecting a Rapid Prototyping Source
While there are many facets in selecting a prototype source, by asking a few of the right questions up front, you can quickly determine if a source meets your unique needs.

What type of rapid prototyping service are you considering?
Know up front whether you are dealing with a service bureau, broker, or an actual prototype provider...and if the last, what types and levels of service the provider offers. All types of providers have their utility, but unless your design is certain to go through the prototyping process trouble-free, higher levels of service and capability will make faster, less costly results possible.
How friendly is the interface...including the quotation process?
Uploading design files to the prototyper should be simple and fast, pricing quotations should be returned promptly, and clear options for payment presented. A weak user interface wastes time, and by inference, money.

How far along the production chain can the online service take your product?
The right prototyper will potentially be able to take a project from the “design on a napkin” stage to millions of units of annual production—or be able to step into the process at any point to troubleshoot problems or suggest possible areas for either design or process refinement.

How flexible is the provider?
A niche prototyper—such as a service bureau—is most suitable when you are certain your design is essentially flawless and you are certain that no problems will crop up when the model is being created. Conversely, paying for more than is required can hurt the financial performance of your project. In most cases, it is most advantageous to deal with a provider that is willing give you exactly the services you need for the particular project in order to reach your production objectives. The provider should even be able to offer process development engineering services for secondary product operations such as decorating processes.

Does the provider know how to run lean to keep costs down and improve efficiencies?
By focusing on creating a “lean environment,” the right prototype developer can find time and cost savings where they may not be immediately obvious. For example, part travel distance during the production process can be fine-tuned for significant reductions in material and part flow, travel, and labor time. By helping customers manage inventory, leading prototype developers can reduce lead times by 60 percent or more. The prototyper should also be constantly looking for ways to cut lead times and costs.

If there is a problem during the prototyping process, will you be contacted by a knowledgeable person directly involved in the project?
CAD files can be corrupted. Designs can prove unbuildable in their original form. The top-level prototypers devote personal attention to quality and functionality, as compared to generically outputting whatever was submitted. Someone involved in creating the prototype should contact you directly when a problem crops up, whether that be an issue with the file, the design, or both. At the basic level, the prototyper should be able to at least provide instructions on how to modify the database of attributes in your design to...
allow the prototype to be produced correctly. Better, they should know what to do with your database in the process of refining your design. Eliminating back-and-forth iteration can make the process much smoother and generate results faster.

How safe is your intellectual property when it goes to the prototype provider?
Outsourcing is common in rapid prototyping. Knowing where your CAD information is being sent is critical to managing your intellectual property. In the best case, your prototyping project will be produced in-house by the service provider. If the vendor you have chosen outsources to a subcontractor (and it is critical that you are aware if this is the case), make certain your design is protected by any necessary confidentiality agreements. This is especially important in cases of international outsourcing, where standard agreements may not be enforceable.

What range of services is offered?
In evaluating potential prototyping partners, look carefully at the available services, and determine what you require to complement your internal capabilities. In general, a full-service prototype source should be able to offer a wide array of prototype services, including both CNC-cut and conventional rapid tooling, as well as engineering resources to support your product development:

- **Project and program management.** The provider should understand your needs and your development process, and be able to provide you with personalized service to assist you through the phases of your process.

- **Full engineering and development capabilities for you to choose from, including:**
  
  **Industrial designers,** who can combine creative concepts with engineering and production to provide manufacturable design direction.

  **Mechanical designers** who can make design for manufacture (DFM) or design for assembly (DFA) suggestions or refinements to optimize design for the intended manufacturing process.

  **Mechanical engineers** who can perform predictive modeling (structural, mold flow, thermal analysis, etc.) to reduce the number of physical prototypes and testing cycles required.

  **Materials engineers** who can recommend suitable materials and perform material testing to ensure that parts meet design intent.
Tooling engineers who can develop the right tooling concept to fit your cost, timing, and tool life requirements.

Quality engineers to support quality system requirements for your industry.

Cost estimating engineers who coordinate and develop competitive, clear quotations.

Processing/manufacturing engineers to develop, improve, and validate manufacturing processes in preparation for product launch.

Packaging engineers to streamline and optimize packaging methods and processes.

The Biggest Threats to Your Product Development Process ...and What to do About Them

Issues can arise in product development, and a well chosen prototype partner can help you overcome obstacles. Be prepared to deal with the following potential scenarios:

- Competitors beat you to market.
  Solution: Work with a prototype developer that can provide concurrent engineering and complement your internal team to enable shortest time-to-market.

- Confusion results from working with several vertical niche providers.
  Solution: Use a single provider with a fully integrated array of service offerings, allowing you to eliminate duplicated efforts and manage fewer suppliers.

- Risk management is a concern.
  Solution: Your prototype provider should have a long track record of success in partnering with its customers to bring products to market. The provider should also have familiarity with your market and its unique quality system requirements in order to select the right prototype process for your product development phase.

- You lack sufficient internal resources to bring the product to market.
  Solution: Your prototype provider should have extensive experience in many aspects of product development and manufacturing, which will allow

Successfully prototyping that leads to timely product launch requires integrating a wide range of engineering knowledge, from initial design through final product packaging. None of the components of the process can be ignored.

Rapid injection mold tooling combines the basic elements of CNC-produced tools with further refinements. Electronic discharge machining (EDM) is used in combination with materials such as hardened steel to produce molding tools that are very close in structure and function to final production tooling.
you to choose the services you need to complement your internal resources. This makes engineering a truly variable cost.

- **The design is unproven prior to production kick-off.**
  *Solution:* Work with a prototype source that offers complete design verification and testing capabilities to supplement its prototype processes, and has the understanding of your product development process to help you select the right prototype path in preparation for production.

- **Selecting members of the supply chain—and determining their level of involvement—proves problematic.**
  *Solution:* Deal with a single supplier that is capable of providing not only all of the technologies and engineering expertise necessary for producing a finished product, but can also manage all of the elements in the process. In general, the more experienced and widely capable the supplier you select, the greater the likelihood of generating finished products that meet requirements for quality, speed-to-market, and total cost.

**Conclusion**

Rapid prototype services give you the potential to bring new designs into the market as quickly and cost-effectively as possible. By selecting the right prototype development partners—and in devising the best strategies for downstream refinement and production—you can introduce innovative products at speeds never previously possible. Ultimately, the greatest value in prototype development is derived from working with a full-service supplier that employs a consultative approach to produce the best results. Overall, the fastest and least expensive path to market is to work on prototype development with the end production process in mind.

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