



Ultimate Guide to Low-Volume Plastic Injection Molding

ABOUT THIS GUIDE

Learn to Bridge the Gaps From Product Design to Prototype and Production

In this guide you'll see how low-volume plastic injection molding allows you to to market, test and perfect your design without the need for high cost, multi-cavity production tooling. You'll how you can optimize low-volume production runs and product testing, reduce costs, risk, and beat your competitors to market.

This guide was adapted from Chapter 6 of *Better Be Running: Tools to Drive Design Success* by Ronald L. Hollis, Ph.D., PE.

Low-Volume Injection Molding

TO BRIDGE OR NOT TO BRIDGE

“As with most things in life, folks tend to focus on the end game, the score, the finale, but choose to ignore the many critical steps and decisions that are made during the journey.”

QuickSMART

D**efinition:** Low-Volume Injection Molding (LVIM) is a manufacturing method that creates injection molds or tools to produce functional parts from thermoplastic in short runs of up to typically 50,000 parts. Significantly faster and cheaper, LVIM offers the same quality, accuracy, and tolerance as production tooling, but without 2D drawings.

Why You Need It: To reduce wait time; to compress production time; to make parts while your production tool is being produced; and to deliver parts to your customer in two to four weeks, instead of eight to twelve weeks with a standard production tool.

Ideal Uses: Simple, single-cavity tools; a “bridge tool” in aggressive product development schedules; low-volume requirements

for applications with a short lifespan; and is sometimes used to test heat-resistance and functionality in end-use materials.

Low-Volume Injection Molding Basics

Throughout this book, you've learned about options for making a prototype or part using Stereolithography (SL), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Cast Urethane (CU), and Computer Numerically Controlled (CNC) machining. These fabrication processes are all used to verify that a design represents the intent of a product. Now it's time to get tooling made. From tooling, you will produce end-use plastic parts. Your choices are LVIM, production tooling, or a combination of both.

LVIM has existed as long as production tooling, well over a hundred years. In 1868, John Wesley Hyatt, a US inventor

QuickTip: The labels "tool," "tooling," "mold," "mould," "molding," and "moulding" are all used interchangeably throughout the industry, causing great consternation to outsiders. Similarly, a "tool maker," a "mold maker," and a "mould maker" all make the tool. Additionally, a "molder," a "processor," and an "injection molder," make the parts. It's all good!

with hundreds of patents, was the first to inject hot celluloid material into a mold to produce billiard balls. He was looking for an alternative material to traditional ivory. The injection-molding process remained the same until 1946 when the first screw injection molding machine revolutionized the plastics industry. Today, almost all molding machines use screw injection molding to heat and inject plastic into tools or molds.

Contrasting Low-Volume to Production Tooling

The term "Low-Volume Injection Molding" means different things to different people. To a designer, it may be a tool

that is used to make a relatively small number of parts. To a tool maker, it may be a tool that has been built to demonstrate a strategy for making the production tool for a complicated part

and to verify if it will perform as anticipated. In the current world of product development, the use of LVIM is a critical strategy to expedite development. By leveraging the advantages of injection molding, the developer is able to get his or her product to market faster without jeopardizing the result or increasing risk of failure in the complicated world of production tooling.

Knowing the key differentiators between LVIM and production tooling will help you make decision tradeoffs as your product moves forward into the most critical and expensive phase of manufacturing. Being lower in cost and much faster to produce, LVIM means that you can get your product to market faster. The simplicity of the LVIM—usually a single-cavity design—allows faster creation, whereas a production tool with many cavities takes much longer to build. Low-Volume Injection Molds have a short life span and can withstand making up to 50,000 parts, while production tools live a long time and have the strength and durability to make millions of parts. In low-volume production, the design goal is to keep the tool simple and use manpower to help process the parts since the volumes are lower. In production, the tool is designed to be mostly automatic which reduces the cost per part. LVIM typically does not need water lines; however, production tooling does require water lines for cooling and would be included if it were to validate a tool design. Water lines add complexity, time, and expense to the production tooling process.

Additionally, LVIM typically does not have as many moving parts, actions, or features as a more complex production tool. Lastly, LVIM is typically made of aluminum or soft steel, requiring two to four weeks to make, while production tools are typically made of high-quality steel, and are deliverable in eight or more

QuickTip: Injection molding is the most common manufacturing method for making plastic parts. A tool maker creates the tool from steel or aluminum. Under high pressure, molten plastic is injected into the metal “tool” or mold cavity, filling the inverse or negative space to make a positive-shaped part.

weeks. This key difference in delivery times makes LVIM a priceless “bridge tool” technology, enabling part delivery much earlier than the production tool.

Impact of CAD and CAM Advances on Product Development

Limited in the past 20 years, the product developer’s option to use the LVIM process opened up as a result of the growing rapport and eventual marriage between CAD and CAM technologies. Evolving CAD solid models merged with changing CAM technologies that were enhanced to handle these complicated models. Through the ever-deepening marriage of CAD and CAM, the product development and manufacturing worlds have now absorbed the reality that a product can be designed and produced in a matter of days. This time compression is a direct result of electronically contained data in a file that is now transportable to all phases of tool making. Significantly valuable to the product developer, this technological evolution is nothing short of amazing.

In the early ’90s, a product developer’s only option to fully produce a part—using the end-use process with the end-use material—would be to buy the production tool and hope the design worked. At that time, it took 12 or more weeks to have production tooling produced at a high cost. As an example, imagine that it is 1990 and a product developer needs a new widget made out of a special thermoplastic to test the design. He has models made from wood or even machined plastics, but these prototypes do not represent the final part very well. Suddenly, a new process called Stereolithography appears and promises that you can now get your “plastic” part just as you designed in a few days for a fraction of the tooling costs. At this point, the product development world responded with a big “Wow!” to the rapid prototyping (RP) revolution. While time and cost impediments had spawned the need for prototypes to verify designs, the advent of reduced dependency on production

tooling to test the form, fit, and function of a part. This change forced the tooling industry to regroup and evaluate how to stay competitive. Eliminating production tooling time and expense, LVIM became an alternative solution, and resulted in a major technological advantage to the manufacturing sector.

• The Wall Tumbles Down

Prior to the marriage of CAD and CAM, a virtual “Berlin Wall” divided the disciplines of engineering and manufacturing. Engineers designed tools in 2D and sent drawings over “the wall” to be interpreted by manufacturing in its own language. When CAD and CAM merged, the wall came down and reorganized the process flow while eliminating wasteful steps. A paradigm shift ensued, proving that tooling could be made in days instead of weeks.

Since that time, product developers have had over 15 years of development to assess the evolutionary promises made by technology to discover which ones were kept, and more importantly, how, why, and in what context. By now, the limitations of each process are fully known.

As necessity and competition drive all things to be better, it turns out that injection molding is also competing with additive processes that have displaced many molding opportunities. While tooling did not change much in the 60 to 80 years prior to this phase, the interrelationship of CAD and CAM now provides clear technological advantages while forcing the old tooling mindset to upgrade at warp speed.

Amazing to the younger generation, you can still find “dinosaur” tool makers with their heads in the sand. Outmoded tool shops from the ’50s and ’60s, once big fish in a small pond, don’t realize the Ice Age has come and gone. The old guard mold makers will actually argue that none of this “new technology” works or even exists, which is sort of like arguing about whether

QuickTip: Never shake a baby and never weld a tool before texturing.

there is an “information superhighway.” “We don’t need nunna that,” is their typical refrain. Of course, new manufacturing processes are available and they do work. Widely accepted around the world, LVIM is used every day by product development companies. Clearly, only those who embrace the new paradigm manufacturing will be victorious in the business of the future.

More about Production Tooling

“Production” is a relative and nondescript word that means different things to different people, depending who they are and what they need. By now you know how to make and verify individual prototypes and parts as quickly and economically as possible. However, **the purpose of product development is to produce an entire product**, usually consisting of an assembly of individual parts. At this stage of tooling, a product developer will have to make tradeoffs between LVIM and production tooling, or both. Since production tooling is the final, most critical, and most expensive step of manufacturing, a working knowledge of tooling options is essential for choosing the best production path for your product. A product developer will invest thousands of dollars on production tooling so he can make thousands of parts for a product. All of the previous costs in the design and test phase will be only a fraction of the total product development process.

QuickTip: Production tooling is the tooling or mold required to make injection-molded plastic parts. The plastic parts are the production parts required to assemble the end product for the consumer.

What makes a part “production” versus “non-production” is a judgment call, usually implying quality standards. With production parts, the highest levels of quality and functionality of the part become critical. Production

also implies higher quantities of parts.

Both LVIM and the more complicated production tooling are made by essentially the same process as outlined below.

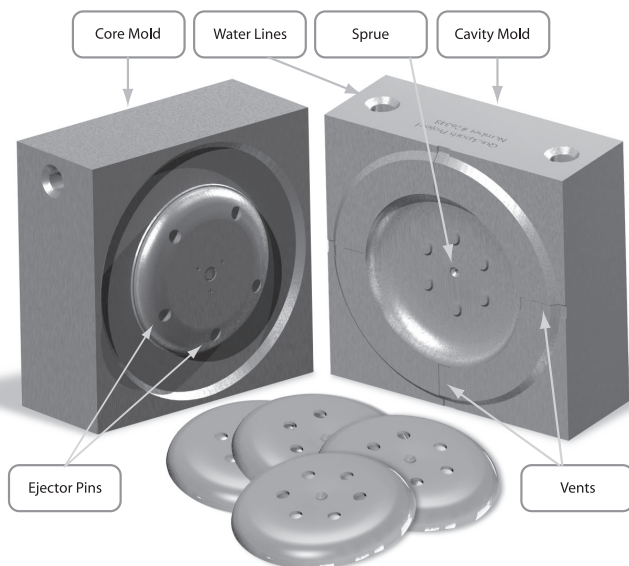
■ Process of Mold Making

Making an LVIM is a fascinating process in which you create something to create something else. One of the major challenges in the process is that you must create a mold or tool that can be used as a receptacle for molten thermoplastic that holds the inverse or negative shape of the part you desire. While this sounds simple enough, some special knowledge is required.

Making the physical tool is just a piece of the battle. The part geometry you design must be conducive to the molding process, and the end-use material must be conducive to the part as well as the mold. The many variables of the process—design, materials, actions, and expectations—make the process of getting from tooling to parts a challenge.

The more efficient LVIM process is similar to the tool making process in that it has existed for over a hundred years. As with sculpting, the tool maker eliminates what is not required and keeps only what is essential.

LOW-VOLUME INJECTION MOLDING (LVIM)



Step by Step: Making an LVIM

Mold making is a complex science that requires a high level of expertise in design, materials, and physics, along with artistic and intuitive insight, all part of the mold maker's trade. A highly valued and specialized craftsman "begins at the beginning." He starts with a great plan for a well-designed part and follows through with flawless execution, resulting in a very smooth, high-quality injection mold.

If those of you who are engineers are now scratching your heads, you are not alone. For some reason, this valuable mold-making module is not taught in engineering school. Here's an important addition to every designer's knowledge base. Step by step, this is how you make a mold.

1. Plan how to make the mold.
 - a. Assess the part for the injection-molding process or Design for Manufacturability (DFM)

When designing a mold, make sure it is conducive to injection molding. The design process for plastic parts is critical, taking into account the "moldability" of a shape. With today's easy-to-use CAD software in the hands of very "green" designers, it is common for parts to be designed that can be prototyped successfully with SL, SLS, and FDM, and accepted by the customer, yet still unable to be injection molded. This costs your company thousands of dollars in errors, issues, and lost opportunities. Early in the process, the expert tool maker closely considers all that could go wrong with a design. Defects that result from poor design and require costly rework arise as lack of draft, parting line problems, poorly fitting ejector pins, poor materials selection, feature deformation, and tolerance errors. The next steps happen electronically in CAD during your design process.

- b. Determine the parting line of the part.

The tool designer visualizes where the tool will come apart in two halves for part release. The line that is formed at these mating surfaces of the tool is called the parting line. The parting line choice is important because it affects the aesthetics and possibly the functionality of a part. Also, the parting line is subject to variability as the tool is processed. As the tool wears, a lot of activity occurs at the parting line where the halves meet. The parting line is susceptible to issues of deformation that occur when the mold is not precisely mated to close completely or is pushed apart under pressure. The resulting gaps fill with unwanted material called “flash.”

- c. Create the part negative from the mold halves.

Working in CAD, the mold maker orients the part for the parting line within a virtual block of material. Next, he does an electronic subtraction of the part to leave the negative shape of the part in the work piece. This will provide two new parts, core and cavity, that contain the negative or reverse portions of the part being designed. The core and cavity meet at the parting line. This process happens simultaneously in CAD so that it appears as a single piece.

- d. Determine sufficient venting for the mold.

The tool maker visualizes and designs the best escape routes to vent air from the tool as it is filled with molten plastic. Vents are needed to prevent voids and bubbles caused by trapped air. When the injection mold process begins, heated plastic quickly displaces air from the tool. The vent allows the air to escape under pressure. The venting of a part is typically tuned during the mold testing which may require new vents or changing the vent design.

- e. Determine the best ejection system for the mold.

After the plastic is injected into the mold, the part remains “stuck” until the mold halves are released or pulled apart. The

new plastic part still needs help to loosen and eject from the mold in the same way a cake needs help in releasing from a cake pan. In injection molding, the process uses ejectors to push the part out of the mold. Ejectors are strategically located pins that push the part from the mold after it has solidified and is very hot, without deforming it. Ejection must be designed to be a part of the process without human intervention. If the ejector system is not done well, the part will stick in the mold and possibly cause the part to deform with extraction.

2. Machine the mold halves with CNC and EDM.

After the tool is electronically designed and all key decisions have been made, the machinist's physical work begins. The CAM software technician processes the data for the mold halves to be machined with CNC, making this process very easy and versatile. Also, some features are processed with an Electrical Discharge Machine (EDM) using an electrical charge to burn away the excess, unwanted material. Today's software is highly sophisticated and easy to use. Built on the same interrelated model as the CAD data, the CAM output will change automatically if the CAD data changes. High-speed CNC machines today can also cut metals faster, but the time advantage is really just incidental. The real power is in the CAM software and the CNC process.

3. Mate the halves for fit.

After the mold halves have been completely processed and machined, the tool maker mates them together. Mating surfaces is a high-precision process. The end result must be very close to perfect, with no gaps or misalignments. There are many tricks of the trade, such as an ink stamping process called "bluing." Bluing is used to check for the transfer of ink to the other half of the mold to ensure full mating of mold halves. (An interesting side note is that the US typically uses blue ink while China typically uses red ink.) The critical need is for the surfaces to mate perfectly before continuing the process. If not, only expensive

future rework can fix this error. Mating has a major impact on the overall quality of the parts that come from the mold, and it can add extra “features” from the mismatch called “witness” lines. If a small gap between the two halves goes undetected, then extra material will be squeezed into this gap, leaving obvious traces that may ruin the part. It is common that during the mating of the mold halves that the molds need to be polished so they are very smooth to produce the best parts. Polishing is a very time consuming process.

4. Assemble the mold.

Mold assembly is where a real time drain can occur. After the mold halves have been completely mated, they are assembled with supporting hardware much like a 3D puzzle. Supporting hardware includes fitting every piece that is required to make the mold workable, such as ejector pins, actions, and alignment guides. By assembling the two halves with all hardware, the tool maker ensures that, for the first time, all pieces are available and assembled correctly. Time drain can occur if parts of the mold have been forgotten or were incorrectly made, such as slides or lifters being too big or fitting too loose. A small but critical error like this stops all progress while the seemingly insignificant pieces are reworked.

5. Install and test the new mold.

The trial run with the injection-molding press is where the “rubber meets the road.” This step reveals whether all of your previous work comes together or falls apart. The molding processor takes over from the tool maker and hangs the mold in the press. He shoots hot plastic into the mold as a trial run to see how it performs. He hopes that a perfect replication of the part design will result, but this would be uncommon on the first trial. As with most creative processes, iterative changes are required. The first shots are used to identify tooling problems or design issues. A plastic part stuck in the mold can mean many things,

most likely that the ejection system is not working or there is not enough draft designed in. At this point the tool maker's "artistry" is required to diagnose the issues and make the required improvements to the mold. It is a challenge to predict how long it will take to get the mold just right.

6. Make parts from the mold.

Once validated, the mold is now production-ready. The operator installs the mold in the injection molding press. Plastic pellets are funneled from a hopper, then heated and forced under extreme pressure into the mold cavity. Within seconds, the injected plastic solidifies into the shape of the part. The mold then opens automatically and ejects the newly formed part. After the mold ejects the part, the process repeats.

■ LVIM Applications—Everything is Everything

Look around you. Practically everything is an injection-molded part. If you tear apart any of your handheld gadgets—cell phone, tape recorder, computer mouse, electric toothbrush—you will discover a multitude of injection-molded thermoplastic parts. From the handle on your lawn mower to the produce drawer of your refrigerator to the buttons on your radio, you sit at the center of a plastic injection-molded universe.

Industry Overview—A Nerd's Eye View of LVIM

With current technologies and the growing acceptance of LVIM, applications of this process continue to expand. LVIM has now become a standard element of the product development process. Decades before LVIM, a production tool was predominantly focused on proving that a part could be molded successfully. In other words, product developers had to use full-on production tooling to validate a part; there was no intermediary refinement process to see how the part would "behave" in reality. But the LVIM process has evolved significantly with the use of CAD and CAM technologies. It is now considered a very useful technology in the iterative development process.

There are many ways of using this process to get your products to market faster. Product developers often use a “bridge tooling” strategy that includes both LVIM and production tooling, either in parallel or in sequence, to support their goals.

Applications for LVIM are found in every industry sector: industrial, automotive, medical, lawn and garden, and consumer electronics. Close tolerances and high-end appearance are ideal for today’s short run projects.

Benefits—The Buzz is Real

In defining your best strategy for compressing product timelines, consider the benefits of LVIM. Product developers are catching on to its powerful bridging capacity used to bolster the front end of larger production projects. **LVIM provides the only solution for creating a few real parts for functionality testing in the end-use material.** This short-run tool is priceless when it comes to garnering investors in early market evaluations. Using LVIM as insurance provides additional safety to your bottom line.

• Short Run Needs

Product developers use LVIM for short run needs when they need a few thousand parts to get the product to market. Since the LVIM process is fast and cost-effective, it’s a great way to get low volumes of parts in the end-use material and beat your competitor to market. LVIM is useful in many situations in which you may not be sure of the market’s demand for your product. It’s also useful if you’re still trying to overcome design or technical challenges. Essentially, an injection mold is a dispensable or disposable tool that has the sole purpose of creating a few parts that look like the production parts.

LVIM is commonly used for short runs in medical and industrial sectors, situations in which the product already has a very low-volume requirement and may have many phases of iterations planned into the design. These application types require much process flexibility and the ability to get parts fast and economically. Short run applications

do not require a production level tool to meet the needs of the product.

• **Real Functionality Testing**

Product developers use LVIM to get a real, functional test unit to verify the product by getting parts made from the specified thermoplastic material. Rapid prototyping processes would not work because they do not produce parts in end-use materials.

LVIM represents an amazing advance in the way products are developed. Not only does it allow the prototyping of parts in the actual end-use material, but also the parts are made in a similar process as the final production parts. Therefore, you are getting an excellent test of how your actual parts will look off the production line.

Using LVIM is a very common requirement in areas in which the part will be used in harsh environments, high temperatures, or at high loads. Product development teams need to know exactly how that part will react, but they don't want to invest the time or money required for a production tool that will need to be replaced. This process allows them to gather new information in prototype testing before investing in production tooling. While the production tooling approach is a very expensive way to develop a product, in some situations it is unavoidable as there is no other way to actually produce the product and assimilate injection molding without the final process. With the use of LVIM in today's world, the cost is very reasonable and the time significantly reduced.

• **Bridge to Production**

Product developers use LVIM as a "bridge tool" or transition to get some of the product to market while their production tooling is being made. LVIM can be a very powerful way to augment a product development strategy. As engineers know, many unknowns and potential risks to the schedule can occur

when the production tooling process gets started. Bridge tooling makes it possible to mitigate the risk associated with the production tooling schedule when an LVIM is made in parallel with the production tool. The product development company can have the latest version of the product started with an LVIM, which typically takes two to four weeks to process. At the same time, the mold maker starts the production tooling process for the same part. By the time the LVIM is done, the design for the production tooling is well on its way—the CNC is ready to start cutting a block of aluminum into the core and cavity of the production tool. The product development company can then begin assembling parts and shipping products to market while their production tooling is being produced—all without risking any schedules or forcing the production schedule to be more aggressive than it needs to be.

• Insurance

Product developers also use LVIM as a backup when they are not certain of production tooling schedules. Often used as “insurance,” LVIM is needed when the product developer is developing a complicated part, using an exotic material, or trying a new supplier. By leveraging the economics and speed of the LVIM process, the product development company can feel assured that it is fully leveraging the resources available without risking the future of the product. Like insurance, LVIM covers the risk associated with the challenges of the product.

• Market Evaluation

Product developers use LVIM to assess the product prior to investor commitments. The use of LVIM is an excellent way to evaluate the market for a product. It is not uncommon for a product to go to market and be ergonomically unacceptable to the consumer if features are inaccessible to the user. The LVIM process allows product development companies to get real-world data on their

product before investing heavily in a production tool that can produce millions of parts. With this valuable marketing feedback, companies can fine-tune their design to perfection so that when they do go to market, product success is guaranteed.

A Very Tall Tale—Johnny Quickparts Goes to China in the Year of the Pig

On a frosty December day, Mr. Overrun seemed overjoyed about getting an order for 500,000 purple plastic Easter Bunny Radio (EBR) housings. The housings had to be engineered with a tolerance of ± 0.005 inch (five thousandths) and the housing halves had to snap fit tightly, able to withstand being thrown by a mad toddler. With more fanfare than usual, Overrun asked Johnny to lead this important project using China. Acme's president, the rarely seen golfer type, had just pinned Overrun in the men's room and asked him why he hadn't sourced in China yet. Overrun excitedly told Johnny that this new mandate came from the president's golfing buddies, so it had to be true. Acme could save millions in China! "Hell, it can't be that different from the US," Overrun said. "Enjoy the junket and bring back a few numbers to satisfy his imagination." Johnny agreed with a handshake. The boondoggle was on.

The customer was none other than the world's most beloved discount retailer Pal-Mart, selling everything from apples to zippers. "Project EBR" had to be assembled, packaged, and shipped, no later than March 1st. The bunny radios would be on the shelves eye-to-eye with smart shoppers well before Easter. To reduce production risk, Pal-Mart ordered two lots of 500,000 from two competing product developers, Acme Design and its dreaded competitor, SCROO-U Unlimited.

Word got around at the American Society of Mechanical Engineers (ASME) chapter meeting that SCROO-U's

lead engineer was all puffed up about beating Acme to China. Johnny's nemesis, Todd Hubris, was really sharp and good-looking to the point of being scary, but he had no soul. Johnny considered him an arrogant know-it-all and had always politely refused Todd's sarcastic professional invitations to Inventors Pizza Night.

The next morning Todd left a snide but chummy voice mail for Johnny, implying that as engineers they were both above competing against each other to please their company management. Then Todd spilled the beans about his plan to quickly get SCROO-U's bunny radio mold made in China and produce parts there as well: "Eight weeks for tooling, T₁ (trial 1) by Jan 30, shoot parts by Feb 5; deliver parts by Feb 28...then to the Bahamas with my new girlfriend. Did I tell you her IQ is 188?" Todd was rude, rigid, and rough—the three R's of any brewing disaster. As a rule, Johnny did not gab with "professional poison" and did not return hyped voice mails meant only to help make Todd feel *big*. Besides, Todd was dumb enough to give away his entire plan for probable disaster with unproven, unknown, uncertified factories in China. Todd's blabber-mouthing inspired Johnny to win this war quietly and confidently. The battle to win Pal-Mart forever had officially begun, but Todd didn't even smell the blood!

Coolly dissecting the enemy's puffed-up production plan, Johnny could see that Mr. Hubris held a number of incorrect assumptions about manufacturing in China. He had indeed put all of his Easter eggs in one basket. His decision-making left SCROO-U quite vulnerable to utter failure in far-flung regions of China. Worst of all, he had sounded way too sure of himself, to the point where Johnny was having flashbacks to his diaper days. Granny Quickparts used to preach about how "Pride goeth before a fall." In efforts to confound the enemy, Johnny wrote Todd a quick, "professional pal" email which said:

Hey Hubris,

When in China, never insult, put down, embarrass, shame, yell at, or otherwise demean a person. If you do, they will lose "face." In ancient times, a Chinese warrior chief, after losing a battle, would commit suicide if he lost "face."

Get Wise,

Johnny

Johnny put on his headset and downloaded snappy Easter tunes to inspire a winning solution. A "bridge tool" strategy would require making two tools: an LVIM for short-term success and a regular production tool to meet the 12-week schedule. This bridging strategy would doubly ensure the success of "Project EBR." He could relax on his first international junket knowing the job was foolproof in spite of any mishap in China. He also hoped his global savoir-faire would impress Helen Helpalot of Quickparts.

Johnny checked Pal-Mart's CAD file for design for manufacturing (DFM), then uploaded it to Quickparts.com. Within 10 seconds, Helen called him squealing in delight. She praised his high-level global thinking for ensuring early delivery while cutting costs. A double-barrel production approach would feature the first tool, an LVIM made of aluminum, as the insurance factor. The LVIM, made in the US, would be ready in four weeks, and Johnny could deliver 100,000 parts also run in the US, six weeks ahead of schedule. In parallel, the second tool, a steel production tool, would be made by the Quickparts factory in China with qualified, focused engineers tracking the tool every day. The production tool would be ready in eight weeks, and 400,000 parts would then be run in China to meet the Pal-Mart deadline of March 1st. On a hunch that Todd might crash his job, Johnny then asked Helen to ship the production tool back to a local molder in the US where additional parts

could be run if needed. Feeling extra witty, he reminded her that opportunity is where preparedness meets someone else's bad luck. Helen laughed out loud and added, "Oh Johnny, your production approach is uncanny. It sounds just like our Hybrid Manufacturing Strategy that sees the world as a superstore—mix and match to get exactly what you need; build the production tool in China and move it to the US for processing." Johnny agreed with her that Pal-Mart would love him for delivering 100,000 bunny radios early, while making sure his production tool would check out in time to deliver the rest at a super low cost. He also agreed with her that only a real Marlboro man can "grab the globe" and think this way. "Yes, Helen," he grinned, "the world is *our* oyster." Those must have been the magic words to unlock Helen because she quickly ensured him not only VIP treatment during his China factory visit but also a Deluxe Boondoggle Enhancement (DBE).

Johnny couldn't wait to check out his T1 parts in the Far East. He envisioned the historical importance of "East meeting West" in manufacturing. More importantly, he imagined endless mountains of steaming rice and Peking Duck on his expense account. He couldn't wait to try the deadly fire water "By-jee-oh" liquor that tastes like rubbing alcohol, and of course, the eggs that had fermented for 30 years deep in the Earth. If it meant being a gracious goodwill ambassador, Johnny was even willing to taste deep-fried chicken feet. Days before he left, he dreamed of mysterious Chi Gong Masters, the old Chinese guys who break people in half just by thinking about it. He marked the map for a visit to the ancient Taoist Mountain Shrine. As usual, Johnny was open to learning as much as he could about everything.

But leaving the great US for the first time ever, Johnny suddenly felt unapologetically homesick as he crossed the threshold into the East. He first saw China through spontaneous tears; a strange, tessellated world made of running

watercolors and mysterious ancient feelings. The hectic streets of swirling color amid diesel fumes and pungent open-air cooking made a potent impression on Johnny's soul. After a day in Shenzhen, Johnny was in culture shock. Everything seemed too loud. He wrote Sally Savealot in Procurement a postcard that simply said, "There's no God here. But I am popular."

On the street corner, local ladies mistook Johnny for dead American movie stars, yelling out at him: "Hey, Cary Grant," "Hey, Gary Cooper," and the most famous cowboy ever, "Johnny Wayne." At street corners, Johnny peeled the women off his arms and walked away strong and steady. No matter where he ate, his soul felt off kilter. He tapped his work boot heels together three times and uttered, "There's no place like home." But nothing happened. He was still there with 1.3 billion of his closest friends, all hunched over cell phones and yakking with a fury he had never known.

Arriving at the Quickparts factory in Panyu, Johnny suddenly felt better. It was a week before the important trial T1 date, and Johnny had a Tooling Manager, Project Manager, Operations Engineer, and the China Project Manager all by his side. He felt a thousand percent wonderful about getting his project done right by professional engineers. He felt secure when the staff showed him their Engineering Change Order (ECO) system for tracking all changes to his production tool. Johnny could see that all issues and design review information had been tracked and communicated in detail. His team assured him that if anything urgent came up they would call him on his cell phone, amply supported by China Telecom.

This factory had taken all the fear out of his production tooling project. Besides, according to an email from Helen Helpalot in the US, his first 100,000 parts from the successful low-volume injection mold had just been delivered

to a very happy Pal-Mart. So Johnny could afford to take a few days off to sightsee with his lovely translator, known as “月亮珍珠運氣公主好,” translated as “Moon Pearl,” or her American name “Becky.” True to his nature, Johnny used her ethereal name.

Moon Pearl didn’t even wince as their cab driver sped in front of a rickety 18-wheeler whose driver was out of his mind. Johnny gripped the seat as hard as he could and yelled at the driver to slow down, but to no avail. His cab was a bucking bronco. Johnny closed his eyes, said a little prayer, and then let go of everything familiar. If he ended up dead in the middle of China with no God, no church, no friends, and no next of kin to call from his cell phone, then it was just meant to be. By the time Johnny had finished the invitation list to his own funeral, the insane cab driver jumped the curb through a throng of shoppers and screeched to a halt in front of a “Western” hotel. With a flourish, the cab driver shouted and waved his arms, pushing everyone aside to make way for the new king in town, Johnny Quickparts.

By the time Johnny got to his room, he was ready for a beer and a little personalized karaoke. He couldn’t read the Mandarin fine print on the complimentary packet of Chinese Liquid Condom by his bedside, but figured it said: “Only 50% reliable; gets rid of all the girls.”

That night Johnny experienced his first “K-TV,” the kind of mild “high-tech whoring” that even Granny Quickparts would approve of. In a livingroom-like bar, Johnny sat on a sofa and selected one girl out of 15 to hold his hand and sing with him for several hours. Johnny’s girl did not speak much English but was very effective with sign language. Her gesture of tossing a drink down and yelling something like, “Gan-bay!” meant “Drink up!” in any language. She could also wail every syllable of Celine Dion’s *Titanic* love song, “My Heart Will Go On.” Under force, Johnny sang the

song about 10 times before calling it a night. Late in the evening, he politely refused the “upgrade,” whatever that was. Through a drunken buzz, he did retain some learning: the Mandarin word for America is pronounced “Mei Guo” which translates literally as “beautiful country.” He also learned to ask for “mei” hotels and restaurants to end up at more Westernized places. Maybe China was not so scary after all.

Early in his project, Todd Hubris also stayed in China for two weeks and avoided a brush with culture altogether. He read his morning paper, *China Daily*, at McDonald’s and ate lunch at KFC. He controlled his experience closely so that nothing new could ever disturb “Planet Todd.” The factory he had selected was very clean and focused, and seemed to care only about his project. His entourage followed him everywhere, warmly calling him “President Hubris.” He liked seeing his parts on the conference room table, and he liked having 20 people bow down to him. After several days of the royal treatment, Todd felt very secure about his project. He didn’t know this great hospitality would fade as soon as he left the building. He didn’t know the factory would drop his job immediately and give priority to the next visiting “President” from the US. Todd couldn’t even imagine his project would be ignored for the next three weeks.

Todd returned to the US and reported to SCROO-U management that everything was hunky-dory in China. The machines were the same, the software was the same, and so he concluded that manufacturing in China was the very same as the US. Besides, he had proof of daily email status reports from the factory to show that the production tool was progressing well. His trial day, T₁, would be on January 30, at which time, Todd would receive 10 trial parts via FedEx. “Piece of cake!” he yelled to his boss as he left early to make the local Mensa Mixer.

Meanwhile, Johnny was half a world away falling in love with Moon Pearl, his first-ever ka-ka-communist sweetheart. Waiting for his T1 parts in style, the enamored couple hiked up the misty mountain to a shrine where Johnny spent a moment in silence to honor the Jade Emperor of Heaven he had read about. He thought it tragic that Moon Pearl could not relate to prayer at all. A government system that “disses God” wasn’t fair to her or anyone.

When January 30th rolled around, Johnny approved the trial parts for his bunny radio housing. The features looked good, especially the sharp ears and rounded tail. He sent an enthusiastic email to Helen Helpalot confirming an order to run 400,000 parts, then return his production tool to the US.

That afternoon Johnny said farewell to the super-affectionate Moon Pearl. He gave her fresh peach blossoms to ensure good luck in the coming New Year. When she begged him to stay till Dragon Month, which meant April, Johnny was floored at his growing international appeal. To break her spell, Johnny splashed his face with cold water in the men’s room and repeated his basic values out loud with conviction: “God, Grandma, Plastics, America.” He straightened himself and walked straight to his plane. Moon Pearl tearfully waved goodbye, yelling with an operatic style, “Goodbye forever, Johnny Wayne! You da man!”

Back home at last, Johnny deplaned onto his favorite terra firma. Fellow passengers watched as he prostrated himself and kissed the ground with a surge of raw passion for the US. He felt like lingering and cuddling the US but decided that impulse should wait. Back at Acme, Johnny found a number of insecure emails from Todd-centric and wondered what was up with this new wave of man-love from someone he didn’t even like. Todd didn’t say anything about his T1 parts, which led Johnny to believe he didn’t have any. With all the godless colors of the East still

swirling inside him, Johnny raced to Waffle House for the All-Star Breakfast for Heroes with his hash browns “scattered, smothered, and covered.” He suddenly understood exactly what a culture gap is—when there is no equivalent for the language to carry. He knew that his communist honey would be completely baffled if asked to translate his breakfast wishes in Mandarin.

Down the street at SCROO-U, Todd sat, day after day, waiting for a FedEx package of T1 parts. He emailed his factory in China for a tracking number but he got no response. He told his boss not to worry, “Todd’s in charge.” The next day, still no parts, no email response, and no phone call. Todd started feeling queasy, but put on a brave face at the staff meetings. He gave in to unusual, obsessive urges to wear black clothing and sweep the floors. His co-workers noted that perhaps the stress of China was getting to him.

It was February 5th before Todd actually heard from his Chinese factory. The factory manager profusely apologized and said that his government had turned off electrical power for awhile. “But we are back on now and will most definitely ship your T1 parts today! No problem!” the manager blared through the fuzzy-sounding speaker phone.

Despite regular assuring emails, Todd still had no parts a few days later. His frustration mushroomed as he sorted through lame excuses and lies from legitimate-sounding reasons for the stall. A few days later, his FedEx box arrived. Much to his horror, his trial bunny radios looked more like puppies, and they weren’t purple, they were red. The ears were warped and the feet had slightly cloven hooves. A critical feature, the puffball tail, was missing. Todd’s voice cracked when he showed his boss “Project Bunny.” On speaker phone, the Chinese factory manager said, once again, they would fix everything, “No problem.” He promised new bunnies, better bunnies. Purple bunnies

would be remade and sent in three days for approval, “No problem.”

On February 15th, Todd received the second trial bunny radio housings, this time purple, with long ears and tail, but they still had cloven hooves. To expedite things, he decided to order 100,000 of these be-deviled bunnies anyway and hire manual assemblers in the US to file down the hooves. Todd approved the tool and ordered 100,000 parts to be run. He then went searching for a US machinist to do this additional manual work. Todd quickly found that he was going to spend all the money he thought he was saving by going to China in the first place. He felt the heaviness of adding to his problems, rather than solving them. Meanwhile, Johnny was well on his way to successfully delivering large lots of bunny radios to Pal-Mart’s warehouse a week earlier than the deadline.

Several days later, the China factory called and woke Todd up in the middle of the night saying that the molder did not have the required purple plastic pellets. The required GE material was on backorder for six weeks. Meanwhile, Johnny was sleeping like a baby because he had ordered *his* material at project startup.

The next day Todd called a US molder friend to purchase enough pellets for his project and have them shipped to China for a mere fortune. That afternoon, Todd got an email assuring him that the factory would start shooting parts just as soon as the factory received his plastic pellets. The email ended with, “No problem.” Todd breathed a sigh of relief, thinking that he could still deliver a partial order to Pal-Mart by Feb 28th.

When Todd finally confirmed that his plastic pellets had arrived at the factory in China, SCROO-U management breathed a collective sigh of relief. On speaker phone, the China factory manager announced, “No problem. We will run these parts as soon as our workers come back from

New Year's celebration. The factory re-opens in a couple of weeks." Todd had learned the hard way that Chinese New Year is more like a socialist workers' two-week vacation. It happens not on January 1st but according to an ever-shifting lunar calendar or government whim. Todd went into a screaming rant, until he finally blew his stack. Like Krakatoa, Vesuvius, and Kilauea, he erupted for 30 minutes non-stop until, finally, Todd Hubris was a weeping, hot blob in the fetal position on the conference room table. He could not persuade 1.3 billion people to give up their holiday through a scratchy speaker phone, thousands of miles away. In front of SROO-U management, his China factory partner, and the world, Todd Hubris had officially "lost face."

Needless to say, SCROO-U spent thousands of dollars without delivering a single thing and still missed Pal-Mart's deadline. Pal-Mart cancelled the contract and yanked the R&D budget in a matter of hours. Todd took his pink slip to the highest bridge and jumped. On the way down, he thought about everything he would change if he got to live.

Fortunately, Todd lived and learned, and now encourages everyone to think about the consequences of their decisions early in the game. He later went on to become a cashier at Dunkin' Donuts, after a short stint at Starbucks as a barista. However, SCROO-U Unlimited went bankrupt, pensions were lost, divorces were finalized, and other management jumped off bridges—all because of one project leader with enormous blind spots. Todd Hubris, a great engineer, pretty much did "know it all," but he became too content within a closed universe.

Several weeks after his return, Johnny was publicly made a hero at the Annual Cake Walk by Acme Design's rarely seen President. While both Johnny and Bob Overrun got huge raises, Johnny got a corner office and surpassed

his boss with grace and humility. Not at all surprised to hear about Todd's company disaster, Johnny said it proved once again that parts really are the center of the universe.

■ Boring but Necessary—LVIM Design Issues and Limitations

Plastic injection molding is challenging. As a discipline, it offers a degree of unpredictability. No matter how well you design your part, the LVIM process will add other features, errors, and effects that you do not want. These tool design issues are the consequence of the innate limitations in LVIM process. Finding that your trial plastic part has annoying anomalies is part of the high price of producing thousands of the parts fast. **Poor design of your LVIM can result in costly rework.** While engineers tend to think some issues are the manufacturer's call, it's best to communicate with all collaborators early in the process and design-in those decisions on the front end, especially draft. Key elements contributing to excellent plastic design include the following.

Plan the Parting Line Design

The parting line happens wherever the halves of the mold come together and mate. This is where the part halves will meet to form a tighter bond. While this is not part of the design, the process will add a feature to your part and you must be prepared to use that feature to your benefit. One of the issues with parting lines are that they can appear in places that are visible to the user, which may be ugly. They can also affect mating places of the part with other things in the product, or over time can affect the overall tolerances of the part. While you will have parting lines, the engineer needs to design the part to incorporate the parting line into his design to use it or prevent it from affecting the part's functionality.

Draft

Draft is the required slant or slope of the walls of the part that touch the sides of the tool. Proper draft allows the part to disengage quickly from the mold when the process is complete. Most engineers struggle with draft because they don't understand how the part will actually be molded, or they can't get their CAD software to work with the addition of draft. For such a simple feature, it can be a real nightmare in the CAD world to get draft on the surfaces in the CAD model without the model becoming highly inflexible. This user-nightmare is related to the complicated mathematics required for CAD surfaces.

It is common for the engineer to avoid draft all together and push it off onto the manufacturer. This is fine except when you let others control your destiny, you get your destiny controlled. The manufacturer may apply a bigger angle of draft on walls that are critical to your design and thus prevent it from functioning correctly. The manufacturer may also inadvertently prevent mating parts from mating with an increase in angle. The effect of draft is a function of the length of the affected surface and the angle of change. Letting a manufacturer change draft could result in features being bigger or smaller by significant amounts (tenths of inches).

Ejector Pins

Ejector pins make features that are remnants of the process. These features appear wherever ejector pins were located, strategically placed to eject the part out of the mold when finished. While typically they are designed to be flush with the surface, ejector pins can be under the surface or may need to be located on a critical feature that can cause tolerance or interference issues. As the designer, you have little control over the placement of the ejectors; however, if you understand the process of injection molding then you can be sure to indicate ejector pin locations and communicate those to the mold maker.

Materials for Parts

It's all about the materials. At the end of the day, you are using injection molding to make use of great materials that will suit the needs of your parts. The LVIM process is very amenable to these materials and ensures the efficiencies needed to replicate your part quickly. However, the designer must be aware of what he expects from the part and materials, as both are interrelated.

The key issue with the material is viscosity, or how easy it will flow in the mold. The designer must select material that will flow in all parts of the mold before the material cools back to its solid state, or he must design the part such that material can easily reach all areas of the part. If the part has thin features, like cooling fins, and the material is very viscous, then it is likely the tips of the fins will not form completely. However, if the material was less viscous, then the fins would have no problem forming.

Also remember that materials respond differently in the LVIM environment. For example, running the same mold in both Polycarbonate (PC) and acrylic will give you two different kinds of parts because the melt flow and shrink factor of the materials are dramatically different. One automotive company had to pay additional money to convert the mold to run in acrylic because the mold was originally built for PC.

Material selection must always be feasible for the part design. Be sure to choose a material that lends itself to successful molding of your part design. A material that has a high-warp tendency is not good for product applications requiring a strict flatness specification. Tool modifications may be necessary to compensate for material or part design discrepancies.

Aluminum for Tooling

Most LVIMs are typically made of aluminum, and aluminum has limitations.

QuickTip: Over 40,000 thermoplastic materials are currently available to use for parts made with LVIM.

Compared to steel, it does not offer longevity or consistent production quality. Aluminum is not good for molds that run under higher temperature requirements. It can have challenges with cosmetic finishes or smooth tooling surfaces provided by harder material tooling. Since aluminum tools are soft, they can be machined and polished much faster than hardened steel production tools. Aluminum can fail when used for tooling to build electrical connector parts because it can't form long, thin pieces.

One electrical company tried to use aluminum tools to produce connector parts that needed steel inserts. Aluminum was not sufficient for the tooling needs, and the final price approached the high cost of making a production tool.

Tolerances

As with all manufacturing, tolerances exist in LVIM. The standard tolerance is ± 0.005 inch (five thousandths). While we can design the perfect part with the perfect dimensions, we are unable to ultimately produce this perfection. When you are designing with a melted material injected into a void to solidify, maintaining perfection is nearly impossible. The designer must be aware of these variabilities in the design and account for them in the functionality of the part. It is very common for great designs to fail because they cannot be made close enough to perfection to work. This requires that other parts get changed to accommodate the imperfection or the product will have severe issues.

In the tooling world, the prediction of these tolerances and how they are made is somewhat like artistic guesswork since the geometry of the part, material, tooling material, pressures, and many other variables affect the output. As the material transitions from a solid pellet to a liquid flow to the solid shape of the part, shrinkage occurs, which can affect the tolerances of the parts. The amount of shrinkage is a function of the materials used.

Lead Times

LVIM typically takes two to six weeks, depending on complexity. A contributor to the short lead times is the use of CAD

data to drive mold design and eliminate paper drawings to build the mold.

■ Saving Time, Saving Money—Saving Thousands with LVIM

How Do I Save Money Using LVIM?

In manufacturing, **almost everything you can do to save time will save you money.** For starters, build a mold that will support the quantity of parts needed. Use LVIM only when you need a low quantity of parts and are sure that you won't need the capability of a production tool. Inaccurate forecasts of low production needs cause the per piece price to exceed market allowances, thus creating a need for automatic production tooling. If you are going to make 10,000 parts at a time, your service provider should be able to add automatic slides to reduce cycle time and operator requirements which can be costly in high volumes.

Be sure to understand the best use of LVIM over CU for certain designs, since for many designs, LVIM is deemed more cost effective than CU only after running 50 parts or so. Consider producing parts in large batches for use over longer periods of time. In other words, consider running the total parts needed for one year to keep your price per part lower.

There are many LVIM design considerations. Be sure to learn the limitations of the process—radii, tolerances, feature size, and wall thickness—and the consequences they have on design. Design features with appropriate radii for machining can help you avoid the cost of additional EDM work. Keep parts as simple as possible to eliminate the need for hand loads and additional tooling costs. Designing with cutouts or windows for snap features and undercuts means easy access for manual tools down the line. Avoid making design changes and concessions before production.

When designing large tools, use LVIM to create a completely CNC-machineable part to reduce the need for EDM, a time-consuming and expensive process. Material removal is much

faster using CNC. If a part design can allow for complete CNC machining, tooling can be delivered in a matter of several days, depending on complexity.

Always verify that your part is capable of being injection molded using Design for Manufacturability (DFM) rules. This will prevent you from investing thousands of dollars in a production tool that would need excessive modifications in order to actually produce the part you design. Use services to test the design before graduating to tooling.

Informed engineers always verify their design in LVIM to save money. One medical equipment company currently spends \$300,000 per year in SL and then moves into LVIM to verify the part design. Integrating production suppliers in the LVIM process helps everyone with the learning curve of manufacturing a part. An automotive company uses LVIM to verify the part design for their customer. Purchasing LVIMs after the release of the production order gets the customer to sign off early on the parts, before submitting production tooling parts.

Troubleshooting the design with RP prior to making a tool saves on costly rework where small changes to mating or function are needed. Reviewing first article parts completely will also catch defects and prevent costly production of unacceptable parts. Be sure to sample the mold in various materials, colors, and textures before committing to a run.

Another money saver with LVIM is that molding issues can be worked out in single cavity versus multiple cavity tools, while proving out part designs for the function of the application. After the part has been qualified with LVIM, companies are able to produce better, automatic production tooling at a more cost-effective means. LVIM also provides the savings of incredibly compressed timelines of two to four weeks, while creating an automatic tool (eight to twelve weeks) would hinder getting the product to market and result in lost revenue to the customer. It's important to incorporate parts into the production cycle while the production tooling is being built and coming online for the

customer, saving sales that would otherwise be lost during the tooling process.

Requesting sample LVIM parts can be another money saver. Using functional samples in the assembly setup while your final production tooling is being made can save time when the production parts finally begin to arrive. Marketing samples will also get solid market feedback on a design prior to costly production tooling. Samples are useful in packaging studies as well.

The most controllable money-saver is clearly defining and communicating all part and project specifications up front in the LVIM process. This includes selecting the best end-use material for the design and use of the part, supplying current CAD data for quoting or production, and providing information on the intended use of the parts produced and expected results. Of course, always provide the final file versions at time of order, knowing that the clock cannot start on your job until all data is received.

How Do I Waste Money in the LVIM Environment?

If you do everything you can to save time and save money in your LVIM process, you can avoid these wasteful scenarios.

Many tools are built in error, either due to sending the wrong revision or to hoping that non-conductive geometries might somehow work. Parts with very thick sections undergo a significant shrinkage defect to the entire diameter of the part, causing failure. Expensive tooling changes and engineering change orders (ECOs) are often required to compensate for part design issues.

Design decisions can also waste money. Avoid designing parts that have side actions, and watch out for designs that need multiple threaded inserts. Additional costs hide in parts designed with many side actions. With these parts, customers often expect a much lower price than what they actually get.

Avoid changing design or materials in the middle of a job to save on complex rework time. One automotive company tried to switch from PC to acrylic material after tool completion and

was unable to produce acceptable parts in acrylic. The company had already sold orders for both materials and was faced with having to provide a product made of only one material. Another company provided a part design that was not conducive to good molding. An inner undercut did not work well when ejected from the mold. The company had to change the design and adjust the tool, losing valuable time on an already tight lead time. Also, remember that it's very expensive to change a mold that requires the addition of material in order to create a new feature. Product engineers are faced with designing around inserts when a "boss" and self-tapping screw would be better for cost in the short run and much better for part pricing in the long run.

Wrong expectations are the biggest money waster. Don't expect that a tool with multiple actions or inserts can be made on a shorter LVIM timeline when you really need a 12-week schedule to produce an automatic tool.

How Do I Save Time Using LVIM?

The best time-saver is to make sure that your part is designed for plastic injection molding. Tool build lead times can be significantly reduced if part designs do not require EDM or side actions. Producing single cavity LVIMs for development purposes allows you to do tool modifications quickly. It requires much less time to revise one cavity than a multi-cavity mold.

Always allow testing of parts before releasing production. Choose the best process—LVIM saves more time than CU after only about 50 parts. Schedule your order well in advance of your deadline. Plan ahead to prevent taking shortcuts, which ultimately do not save time.

How Do I Waste Time in the LVIM Environment?

Administrative flubs are hidden time-eaters. Be sure to issue a valid purchase order with the project start, and prepare your finance team to pay the first 50% deposit to get the project started. Always reply quickly to your service provider's request

for design approval or concessions. **Start a project with the final correct files, knowing that the clock does not start ticking until a purchase order (PO) and the correct version of design are with your service provider.** Have realistic expectations about tolerances—it is not uncommon for companies to expect a tolerance of ± 0.001 (one thousandth) when aluminum tooling tolerance cannot meet this.

■ The Keys to a Brand New Amphibious DUKW

By now you know that LVIM is a manufacturing method that creates mostly aluminum tooling or injection molds for producing short runs of up to 50,000 parts. You've explored China with Johnny to witness an aggressive product development race, and you've been inspired to try LVIM as a "bridge tool." You've felt the technological excitement of seeing how LVIM can compress production time and get parts for evaluation early in the process. You understand that LVIM provides powerful insurance on very costly projects. You've seen the world of manufacturing turned upside down and you now understand the winning strategy is called the Hybrid Manufacturing Solution. Enjoy the chaos.

As Johnny would say,

"Entropy Rules!"

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