Low Volume Development Techniques for Plastic Engine Parts

Author(s):
Tim Keighron
Donald Carbone
of Managed Programs LLC (MPI)

Abstract
This paper will describe MPI’s modifications to the traditional Product Development Process for highly engineered plastic engine components, in developing Low Volume Production (LVP) products for various automotive markets, such as the After Market Performance / Racing and Service replacement parts. We will describe the development methods from concept to industrialization and the use of modified manufacturing processes including some processes developed specifically for this Low Volume Market. We will also describe our adjustments to traditional high volume production processes used in a novel way to balance per piece cost and upfront tooling costs, resulting in a total cost improvement while producing a product nearly equivalent to a product developed for more traditional processes. We will demonstrate that with the use of analytical tools such as engine simulation and specialized tuning methods combined with a true “Design For Manufacturing” (DFM) approach, focused on total value, a highly developed and specialized product, required in low volumes can be made cost effectively. The goal is to produce Low Volume Products at High volume prices and this requires not only a new product development process, but a new mindset focused on the Total Value. Furthermore, this paper will explain NylonmoldTM, a patented prototype and LVP casting process that has been in production for a decade and under development at MPI for over 12 years. We will detail the advantages that NylonMold™ to the development process from timing and cost. Finally, the NylonMold™ has now moved into a viable option for LVP applications for intake manifolds and plans for more plastic engine components.
1 Introduction

Managed Programs, LLC or MPI is a leading automotive intake system design, engineering and manufacturing firm delivering technology to our clients. MPI is a USA based company founded in 1997 in Auburn Hills, Michigan. We have an engineering and sales office in Seoul, Korea and sales offices in Germany and China. At the end of 2011, we have moved into a 37,000 square foot (3,440 sq meter) building in Auburn Hills, MI to enable us to expand our low volume production (LVP) assembly and NylonMold LVP production capabilities.

![Fig. 1.1.1 The above picture is Managed Programs, LLC’s new world headquarters in Auburn Hills, Michigan, USA.](image)

MPI has designed over 100 intake manifolds since its inception for a global automotive customer base of OEM’s, Tier 1 suppliers, aftermarket service replacement, and aftermarket performance companies.

Based on the continual forces of individualization in the automotive market (in fact all markets) there is an ever-increasing pressure moving our industry towards lower and lower volumes, in a sense, further away from Henry Ford’s original idea of the “Assembly line” and diminishing the benefits of “Economies of Scale”. It may not seem inevitable to automotive companies at this time, but this trend is rapidly forcing changes in the entire Product Development Cycle for all products (e.g. electronic and consumer products as a clear example of ever-decreasing product life cycles and increased demands on time to market and new technology) and now even influencing the traditionally slow changing automotive market. Considering this and other related factors such as “product integration” (or modularization) and a global market place with many new small and medium sized enterprises, a “new Product Development process” is required for improved efficiency in the production of products customers WANT to buy with ever-increasing diversity and change. In effect, “Low Volume Production” done cost effectively will facilitate this demand. To accomplish this we have adapted the traditional product development process for such components by implementing Henry Ford’s principles of “Economies of Scale” into the Product Development Process itself, not just the manufacturing process.

In this paper, we will review step by step the process changes and principles developed to increase efficiency of design, reduce tooling cost and even the efforts made to improve the production processes themselves to reduce fixed cost and drop overall development costs to make viable, lower and lower volume applications for use with Engineered Plastics. This type of system change cannot occur all at once. In fact, our process has taken over 10 years to develop and we continually find new improvements daily, but the key is to have an open mind and focus on Total Product Value. In principle this entire process is an effort to reduce cost, but NOT in the traditional sense of the automotive world today, where a customer demands it and suppliers concede profit levels or die. This is a structural change in the development process that designs OUT cost by matching the demands of the
product to the demands of the materials and manufacturing processes available while meeting the ultimate investment and total product cost requirements of the market place. There are many barriers that need to be challenged which prohibit the use of technologies originally designed for High volume manufacturing, which is the core of current automotive manufacturing today. Many companies have made great strides in Design For Manufacturing using cross functional teams and concurrent engineering to generate great efficiency improvements, but to continue this increase in efficiency further, with the compounding factor of lower part volumes, fundamental change in the development process itself needs to be undertaken. Small but significant changes in methodology can show great improvements in quality and cost, while opening up room for more innovation to drive change, instead of just reacting to it. To take advantage of change, find new markets and new product opportunities.

This paper will demonstrate some of the initial steps in generating those changes which will reduce the burden of volume on product cost and facilitate more product diversity, making available specialized products to low volume markets such as aftermarket performance products and racing industry. In addition, these methods can afford more opportunity for localized production in developing markets and finally, greater opportunities for larger scale Product integration of systems not possible with high volume techniques.

2 Definitions

2.1 Product Development

Product development for the purposes discussed herein includes any engineering, analysis, testing, prototyping, tooling, tooling development, process development and or any specialized equipment required to produce a particular product. To be clear; All the required activities to bring a product from idea to industrial reality.

2.2 Terms

LVP: **Low Volume Production** for the purpose of discussion in this paper, is defined as a Volume at which most qualified companies producing Thermoplastic engine components using current methods would consider the programs financially Not Viable, typically this would be less than 25,000 to 50,000 parts per year (this number would vary by company, market and business environment).

HVP: **High Volume production** would be considered as any volume greater than LVP, but more typically in a range of 100,000 to 500,000 parts per year.

2.3 DFM / DFA/DFP

**DFM**: Design For Manufacturability is the process of proactively designing products to (1) optimize all the manufacturing functions: fabrication, assembly, test, procurement, shipping, delivery, service, and repair, and (2) assure the best cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction.

**DFA**: Design For Assembly , the process of specifically designing parts for a particular Assembly process (manual, automatic..etc), as opposed to finding or developing specialized assembly techniques to assemble a product, ie simpler is more effective.

**DFP**: Design For Profitability: is the process of proactively designing products to (1) optimize all the manufacturing functions: fabrication, assembly, test, procurement, shipping, delivery, service, and repair, and (2) assure the best cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction, resulting in a MORE Profitable business model.

2.4 Total Product Value and DFP

![Total Product Value Chart](image)

**Profit = Sales Revenue - Total Cost - Taxes → Maximum**

where:

Sales Revenue = \(V\) (Selling Price)

Total Cost = \(V(m + l + p) + F + S + D + T + B\)

and:

\[ V = \text{lifetime product volume} \]
\[ m = \text{unit material cost} \]
\[ l = \text{unit labor cost} \]
\[ p = \text{unit cost for production resource usage} \]
\[ F = \text{fixed tooling and equipment cost} \]
\[ S = \text{systems cost} \]
\[ D = \text{development cost} \]
\[ T = \text{time cost} \]
\[ B = \text{business cost} \text{ (e.g., administration, advertising, etc)} \]

Fig. 2.4.1 The above chart describes the generally accepted variables affecting product cost and price and the relationship to profit.

For the purposes of this paper we will define Total Product Value, in an integrated and coordinated way. To facilitate this we define as follows;
The Design Determines the Cost

The Product Design controls 70% of all of the costs for the life of a product. By attacking cost at the source, in the design, DFP design principles help reduce cost and increase profits. While attacking piece cost or eliminating waste in manufacturing show some savings, DFP will reduce part count and eliminate entire manufacturing operations which will significantly increase quality and profits.

Conclusion:

The Design Determines the Cost

The Product Design controls 70% of all of the costs for the life of a product. By attacking cost at the source, in the design, DFP design principles help reduce cost and increase profits. While attacking piece cost or eliminating waste in manufacturing show some savings, DFP will reduce part count and eliminate entire manufacturing operations which will significantly increase quality and profits.

Fig. 2.4.2 The above describes the ability to increase profit lies in the knowledge acquisition and concept phases.

To accomplish this, DFP presumes to effect profits from the start of the product development process because this is where the most effect or benefit can be created, as demonstrated above. The difficulty in doing this is that most product developers don’t integrate cost calculation in to the design process until the design is finished, after many decisions, like what process should be used to manufacture the parts or what material is acceptable and/or even the location of the assembly. All these items must be considered at the start to properly utilize DFP. Simply put, the product development process must provide tools to evaluate each of the variables in Total Value equation above. To assure the designer is aware of the impact of his decisions throughout the design process.

Fig. 2.4.3 The above picture is a graphical representation of who effects the Total cost and Hence the Total value of a product.
3 Market drivers and Market conditions

3.1 Product/Process development and change

As mentioned above, there is an intimate link between the product design and the manufacturing process, but in the past this link was more of a burden or limitation to the creativity of the product designer.

Why is this?

Primarily the product is always changing, from new customer demands, new technology and a general trend towards better products. Less obvious is the product development process itself. Product development is by definition a process of change, even today it amounts to a series of trial and error loops –or learning cycles, this basic nature of the product development process and the product designer is driven by continual learning and constant efforts to improve and innovate. On the other hand, from the perspective of the manufacturing process, increased capital utilization is the basic goal; more stable, more consistent and better efficiencies are the nature of Manufacturing. Take for example the 6 sigma process, it is, in effect (please excuse the oversimplification) a means of reducing variation or limiting change.

These basic natures form a diametrically opposed relationship between the Product development and Process development, the less they interact the better (at least in the automotive world of the past). Develop the product and throw it over the wall to manufacturing and they will develop processes to produce that product and finally then it’s up to sales to see if they can sell it, to make a profit.

It is clear today that this is not the most effective means of producing a product. As mentioned in the definitions, there have been many improvements from lean manufacturing to DFP, but none of these deal directly with the problem of increased product diversity and/or lower volume applications. If you want efficiency you must have large volumes for economies of scale, to spread out the cost of capital and the cost of product development. Henry ford was quoted as saying about the Model T, “you can have any color you want, as long as you want Black”. This kind of thinking is no longer acceptable in the market place. So considering this basic nature of manufacturing today, what is the cause? At first glance, it is easy to see that the goal of manufacturing is to reduce labor and increase capital utilization. This is directly from any economics text book: to reduce cost and improve profits, reduce labor and increase efficiency. To accomplish this, automation was used, which increased Capital investment, thereby making utilization of this capital the primary goal of every manufacturing entity. This has been the standard since Henry Ford made the Model T, but today we have a rapidly-changing market place that requires a more advanced approach. Fundamentally, this is the basis of efficient manufacturing with very developed process technologies to produce products with the best quality. We must use standardized processes and operate the equipment as efficiently and consistently as possible. (i.e. No change!)

How do we handle change better in this environment? Recent trends of Concurrent Engineering and DFA/DFM/DFP and lean manufacturing have created great improvements in efficiency, by adapting the Product design to the PROCESS. This is the key to the last 40 years of improvement, in addition to technology developments in automation and new materials and new process developments, as evidenced most clearly in the field of thermoplastic engine components, where all three can be seen simultaneously. But clearly increasing change is the trend.

3.2 Example IAFS

This triad of change culminates in the integrated air fuel system (or IAFS) which as a novel side note, was originally the carburetor, where air, fuel and all controls were integrated into one device, done purely by mechanical means vs. today’s IAFS where integrated Electronic Fuel and Air metering is combined with the engine control unit and any number of other electronic control devices and even air filtering and tuning are combined into one compete assembly at roughly same cost in real dollars as the original carburetors (this is quite an amazing feat of technology considering the extreme level of improvement in control capability).

3.3 The Effect of integration on volumes

With the advent of integrated systems, the IAFS mentioned above as an example, a new difficulty begins to arise. When we combine the air filtering and the air fuel delivery systems into one device our vehicle and engine combinations drive more variation into the product mix and also drive down the number of parts or volume per product application. Because each engine is used in multiple vehicles...
with a common intake manifold and each air induction/filter system is used across multiple engine combinations but only one platform vehicle, the end result is lower volume per product application.

3.4 Global Market and Full Service suppliers

Further affecting this rapid change in product development and partly due to the rapid manner in which this change has occurred, the traditional role of the supplier has also evolved. In the past the casting manufacturing facilities (casting and machining) who produced the intake manifolds were primarily part of the OEM or the OEM had extensive experience in producing castings thereby performing nearly all of the product development internally and even if the casting and machining was not done by the OEM, certainly the design was. But for this field, most OEM’s did not have experience in developing plastic injection molded products and therefore relied more heavily on the full service supplier. In addition, thanks to the material suppliers (a tier 2 supplier) efforts in both material, product and process developments, the true development skill for these products rests more with the suppliers than OEM’s, with the exception of some European OEM’s. This rapid change to plastic engine components just happened to coincide with the Full service supplier trend, where the supplier of the product would participate in its development since the rapid pace of technology development from electronics to materials made it impossible for OEM’s to remain experts in every technology needed keep pace with change.

3.5 Developing vs. Entrenched Markets

An additional aspect change from the globalization trend of today’s automotive market is that in developing markets the supply base is limited and full service suppliers are not available to provide such highly engineered products with relatively new and specialized equipment and processes. This poses a number of difficulties for Thermoplastic engine components. Especially for integrated air fuel systems, which are typically large in size and therefore very expense to ship. In addition, consider the fact that most developing markets don’t start out with high volumes. It typically takes many years to develop the volumes needed to justify the investment for any single application. So far this has only been accomplished by forcing the existing suppliers to move into the new markets, which limits the cost effectiveness of the move to the new market in the first place. If localization of components can’t be accomplished in accordance with the local regulations and using local suppliers, the cost benefits of Plastic engine components is potentially limited.

3.6 Untapped or Niche markets

In the past the market penetration of plastic intake manifolds vs. metal intake manifolds was seen to be limited, at some point around 75 percent of the market, as shown in figure 3.5.1. Regardless of the actual limit, the reason most often given for this limit is the financial viability of Plastic Intake manifolds in low volume. This fact is the single largest reason for the development of the LVP process. If this limit can be lowered, significant increases in market share will be available.

Fig. 3.6.1 The above chart shows increasing trends of thermoplastic engine components in today’s market.

4 The Product Development Process

4.1 Product Development Process and the effects of volume

It is assumed that every Full Service Supplier must have a Product Development Process and each has unique features based on individual experience in either a particular product field and/or manufacturing process. In the case of the aforementioned Plastic Engine Components, most companies use a similar development process, primarily described or developed in accordance with AIAG standards and is primarily patterned after that used by the OEM’s (this is an overgeneralization for sure, but for the purposes of comparison we have simplified the description to a level where we assume most are the same). This process is described in figure 4.1.1. This normal development process may have more or less loops thru each stage, but most programs in this field follow these typical phases. It is commonly accepted that, the more loops of design, build, test, the more cycles of learning, the better the product (a theory not inconsistent with the Toyota production system) in effect the a typical HVP development process is intended for as many cycles of learning as possible, or as many cycles as the program timeline will allow, not what is the lowest Cost manor to get to an acceptable solution.
4.2 Total Value; Cost vs. Quality vs. Volume

To understand this lets go back to the equation of Total Value described in section 1.

If Total Value = Total quality / (Total Cost + Total Time), then as we increase the Total Quality by creating a better designed product, from increased cycles of learning, we see that a direct improvement of Total Value is accomplished, even though we increase the cost of development.

Eventually our question must be what’s the limit?

If we observe that the Total Time is inversely proportional to Total Quality, and if the schedule is primarily determined by the OEM, this variable can be assumed to be fixed and relatively low in significance, since most OEM programs are limited by the overall engine and/or vehicle timeline and not this individual component.

Now our focus can be placed directly on the effect of Total Cost vs. Total quality.

If Total Value = Total quality / (Total Cost + Total Time), and as we recall, Total Cost is a combination of Direct Cost and Indirect Cost. We can relate these to Total Value in such a way as to determine the modifications needed to the product development process for LVP programs (in contrast to HVP programs).

Recall:

\[
\text{Total Cost} = V(m+1+p)+F+S+D+T+B
\]

And

\[
V = \text{lifetime product volume}
\]
\[
m = \text{unit material cost}
\]
\[
l = \text{unit labor cost}
\]
\[
p = \text{unit cost for production resource usage}
\]
\[
F = \text{fixed tooling and equipment cost}
\]
\[
S = \text{systems cost}
\]
\[
D = \text{development cost}
\]
\[
T = \text{time cost}
\]
\[
B = \text{business cost (e.g., administration, advertising, etc.)}
\]

The above Description of costs (as defined in section 2.3) Therefore if we separate terms;

**Direct cost** = \(V(m+1+p)+F\)

**Indirect cost** = \(S+D+T+B\)

We first note that the most significant factors on direct costs, when Volume increases, is the Unit cost, \(m\), \(l\), \(p\) and to some extent \(S\) and \(B\), but increasingly less significant is \(F\), the tooling and equipment costs and \(D\) the product development costs.

Of the indirect cost factors, the relationships to volume are not easily drawn from this simplified equation, but if we assume the following, we can start to make some inferences regarding these data;

It should be clear that we can assume, based on experience that the development cost is primarily independent of \(V\), volume and more dependent upon \(T\), time, than any other variable, therefore these two items can assumed to be fixed (at least for this portion of the argument). Now \(S\), system cost, and \(B\), business cost, are both related to indirect capital investment and overhead usage, these can vary widely, but if properly managed, i.e. each portion of capacity is effectively utilized, then these can also be assumed to be relatively unaffected by volume or at least related to more to a particular companies effectiveness as going concern, than as a significant factor of cost related to Volume (of course this is not completely accurate, but for the purposes of clarity, we make this assumption for now, but this will be addressed at a later point in this article).

Therefore

**Total value** is proportional to \(V(m+1+p)+F+S+D+T+B\)

Now we can see that Total Value, when Volume is increased, becomes inversely proportional to direct costs. Therefore all efforts should focus on this first (which is normal) and conversely when volume is reduced the significance of \(F\) and \(D\) are greatly increased, furthermore it can been shown that it is more than a linear relationship, by the fact that **Total Quality** may be decreased, if any reduction in \(D+F\), would result in a lower Total Quality (as
could be assumed if $D$ is a result of less cycles of learning and a lower $F$ is the result of less or lower quality equipment and tooling).

Now the general conclusions made in the past whether consciously or not, are that the higher the volume the better and the limit to the low end volume is directly related to $D$ development cost and $F$ tooling/Equipment costs.

In conclusion, the effect of volume as it is increased, actually forces priority on variable costs for sure and then likely the overhead costs because to increase capacity we must increase system and business costs. Hence we conclude the product development costs (i.e. development and tooling...etc. as defined in section 1) is of lower concern for HVP programs and conversely of Primary concern for LVP programs with reduced volume.

Actually it can be shown that for HVP programs the cost of development and tooling could be said to be directly proportional to increased total value and hence higher profits by the formula shown in section 1. This could give way to the assumption that increased spending on product development in itself would increase profits, but this is incorrect as it would be limited by the overall business costs ($B$) and System costs ($S$).

4.3 Thermoplastic Intake Manifolds, HVP process example

Now if we evaluate the experience to date, for example in the Plastic Intake market and its relatively short history, we can view the past with new insight and see if our conclusions will correlate (this is not intended to be a proof as historical vision is always perfect, it is just a means of reviewing the past in effort to validate our assumptions). If we look into the transition from Aluminum intakes to Plastic Intakes, the transition was initially resisted. In fact at the start there was extreme reluctance for engine developers to embrace this new material “Plastic”, the advantages of weight, internal surface finish and thermal isolation were all obvious, but the image of plastic was not good and as we all know, most engineers are conservative by nature. They needed significant motivation for them to pursue such a change.

Metal to plastic?

After making this proposal to engine designers in the US during the early eighties, a common reply was heard, “plastic is for toys, aluminum is for pots and pans, we make cars out iron and steel”. So it seemed, the change would not happen without significant effort, if it was not for lower cost, it would not have happened. Since the cost of aluminum intakes and its requirements were clearly understood, using this information, one could calculate the potential savings to allow (or entice) the OEM to accept the risk of change (let’s call it $V \times S$avings)

If we assume the total market worldwide is 70,000,000 vehicles/year as an estimate (2008 production) and the average intake was about $40 to $50 (total market value of $3.15B), then if we calculate the savings per part to be 20% (certainly more is possible but to be conservative this will suffice), we can estimate a total savings of $70M x $45x20% = $630M savings on an annual basis, this is a significant motivating factor and eventually this effort was under taken (not without the help of the material suppliers who saw a huge market for their materials, if only the products could be developed to use them).

Paramount to all engineers is the risk of failure, without a plan for mitigation of this, nothing would change, no matter the cost savings potential.

To reduce risk two things were needed:

A) a robust process for manufacturing and B) a design process which proved the replacement plastic part was at least functionally equivalent to the metal original.

First, the manufacturing process was developed (i.e. lost core molding was developed and then Vibration welding) This effort was lead by key Tier one suppliers in conjunction with Material Suppliers, both motivated by the numbers explained above.

In addition to cooperation with OEM’s, certain testing standards were developed (over time for sure) to assure equivalent performance to the original in metal parts.

Now since we have established the target cost savings, (i.e. 20% of the existing aluminum cost) Aluminum Intake Total Value - $V$ = Plastic Intake Total Value, with this factor it is now possible to calculate the potential profit, up front, and since we now have defined the process to determine all of our cost of manufacture, we just need to calculate backwards and determine if the tasks can be completed with this clear budget.

We must first assume that the general design (or the size and shape of the parts) would be based on a copy from the Aluminum design (as most experienced in this field know today, this is a bad idea, but remember it was only natural to do so then) would be sufficient to calculate Total Cost to produce the product and from the formula above, assuming that Total Time is an independent variable (as explained above) we can state that:

$$\text{Total Value} = \text{Total Quality/Total Cost, where}$$

$$\text{Total cost}= (V(m+P)+T+B+S+(D+F)+ \text{profit profit}}$$

with an acceptable profit included from the start. If we assume indirect costs are proportional to overhead (in some case it can be estimated as a percentage of costs or labor or floor space a reasonable estimate is normally possible) then we have only the Product Development costs.
Low Volume Development Techniques for Plastic Engine Parts

(D and F) to be calculated, to see if the change to Plastic is possible given the market demands identified above.

**Total Al Intake Value(VS)-V(m+l+p)-T-B=S= (D+F)**

Hence, the effort that can be expended to lower the risk in development, to assure success, can be calculated and so long as the volumes are sufficiently high to result in a large enough value for D&F. The Engineers can develop a successful product and the market is open for growth.

From this view we can now see why the Product Development Process for Plastic intake manifolds is quite different than that of an aluminum intake, or many other parts defined more completely by the OEM’s. It was created to replace the acceptable predecessor product, merely at lower price. Total Product Value and Total Product Quality were clear at the start. In addition, there was no need to be BETTER than the aluminum (in fact, plastic intakes can be, but the motivation from the start was really just as a cost savings). In this way the product development process was actually created to fit a need and came with a TARGET COST based entirely on the volume.

It followed the manufacturing process limits, tooling requirements and profit targets, resulting in a completely new product development process.

A real world example of DFP.

In conclusion this dependence of Product Development on Volume affected the entire Plastic Intake Manifold market. Because this product development process was itself NEW, it was constrained not only by Volume, but by the Product Development Process capacity itself (again it is noted that, the capital investment into equipment is the typical constraint for most products, but not exclusively so, in this case)

Result: Limited number of qualified suppliers globally.

Because if the volume was too low the savings over Aluminum, (i.e. VS) was insufficient to cover the cost of D&F, which was in turn increased by the increased efforts to prove with high confidence (and High Cost, further limiting who could develop the skill to design the product), that the product would work against conservative engineers reluctant to accept the new materials.

If we look more closely, the entire product development process was designed to reduce design risk for a particular volume V, a threshold volume was determined by this process and as any experienced person from this industry in the late 80’s and 90s can attest, the transition was fast, money invested was large, all made possible by the large cost savings potential on high volume programs. Based on this information, we can conclude that if the volume is high, then there is a strong incentive to take greater time and effort (i.e. increase indirect costs D&F) to reduce the unit costs of production, reducing total product cost BUT also increasing the Total Product Quality, thereby greatly increasing Total Product Value.

But in the case of LVP this is not true.

### 4.4 Product Development capacity and LVP

Therefore, to maximize this limited development capacity all efforts were targeted at the highest volume programs (in addition to developing more capacity, the basis for the creation of MPI in the first place).

Now let’s move forward to the market today where competitive pressures on cost are much greater, in addition to the fact that our experience with thermoplastic engine components is much greater and plastic is more widely accepted in the market place.

Now it seems only natural that the Product Development Process which was created based on different market conditions should change to match a new reality or at least to support new markets that would benefit from the same products. The only difference is the volume.

<table>
<thead>
<tr>
<th>Untapped Markets for Plastic Engine Components</th>
<th>Advantage of Thermoplastic</th>
<th>Limitation of Thermoplastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine engines</td>
<td>Coreless injection, lightweight, improved performance</td>
<td>Low Volume</td>
</tr>
<tr>
<td>Personal water craft and Snow Machines</td>
<td>Coreless injection and potential for integration</td>
<td>Low product diversity, lack development capability in typical supply base</td>
</tr>
<tr>
<td>Specialty vehicles (industrial fork lift etc)</td>
<td>Lightweight, improved performance</td>
<td>Low Volume, lack development capability in typical supply base</td>
</tr>
<tr>
<td>OEM Specialty Vehicles (high performances)</td>
<td>Lightweight, improved performance</td>
<td>Low Volume, lack development capability in typical supply base</td>
</tr>
<tr>
<td>After Market Performance / Racing</td>
<td>Lightweight, improved performance</td>
<td>Low Volume, risk areas vs tradition, lack development capability in typical supply base</td>
</tr>
<tr>
<td>Heavy Duty truck/construction equipment</td>
<td>Lightweight, lower cost</td>
<td>Low Volume, Risk areas vs tradition, lack development capability in typical supply base</td>
</tr>
</tbody>
</table>

**Fig. 4.4.1 The above chart shows a brief example of new product areas and the advantages vs. the limits or barriers to entry.**

So the enabler of LVP is a NEW Product Development Process that is modified to suit the factors critical to it. First and foremost is the formula for value:

**Total Product Value = Total Product Quality**

**(Total Product Cost + Total Product Time)**

If we look at the formula of Total Product Value as we lower the volume;

For the unit cost, m,l,p, they remain important but they are much less significant as the volume goes down, in contrast to the costs D and F. In fact, these are inversely proportional to volume and hence increasingly important.
and possibly more than just linear relationships as can be shown below.

Then the indirect costs of T, B, S would seem to be unaffected (as in HVP), but not so, if these are to be maintained then it is critical to keep the overall volume in any facility up at the capacity limits (capacity utilization is key to minimizing Manufacturing overhead costs as we assumed above) as the volume is reduced per program, all of these costs must be carried by MORE programs to maintain the efficiency we see in HVP. But this is going to increase the impact of D & F, even more so to maintain the facilities efficiencies.

<table>
<thead>
<tr>
<th>Effects of volume changes (V)</th>
<th>High volume Production</th>
<th>low volume Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material cost, m</td>
<td>More important, &gt;50% of total cost</td>
<td>Neutral, except the low volumes can drive cost up / unit – generally low impact</td>
</tr>
<tr>
<td>Labor cost, l</td>
<td>More important</td>
<td>Less important</td>
</tr>
<tr>
<td>Unit cost for production, p</td>
<td>More important</td>
<td>Less important</td>
</tr>
<tr>
<td>Fixed tooling costs and equipment, F</td>
<td>Less important, especially if lower risk</td>
<td>Very important, risk must increase</td>
</tr>
<tr>
<td>System costs, S</td>
<td>Less important, as the business grows, as long as it is efficient</td>
<td>Best case to neutral, in most cases overhead will go up in significance</td>
</tr>
<tr>
<td>Development costs, D</td>
<td>Less important, especially if lower risk</td>
<td>Very important, risk must be minimized, along with cost</td>
</tr>
<tr>
<td>Time costs, T</td>
<td>Neutral, based on timing of OEM, as long as it is not the limit of the program</td>
<td>Very important, risk must be minimized, along with cost</td>
</tr>
<tr>
<td>Business costs, B</td>
<td>Less important, as the business grows, as long as it is efficient</td>
<td>Best case to neutral, in most cases overhead will go up in significance</td>
</tr>
</tbody>
</table>

Fig. 4.4.2 The above chart shows a brief example of new product areas where thermoplastic engine components can be applied, and the advantages vs the limits or barriers to entry.

One limit is the flexibility of the capital equipment in place in addition to the capacity of and cost of Product Development (i.e. D&F).

We can see from the past, that the Product Development capacity itself in this market has constrained growth (especially into the LVP area). It seems obvious that what capacity there is, will be targeted at the HVP programs.

What could change this?

Time and the Market.

Over time there have been efforts to increase this capacity, globally. This increase has come in two ways, an increased number of suppliers who have developed this skill to meet the market demand both here and in developing markets and specialized development companies who provide this type of Product Development as a Service.

The first is primarily focused on increasing the companies utilization of its internal manufacturing facility and the latter is available for a cost, to any company who wants to create manufacturing capacity without the overhead (not to mention the time to develop this skill) of the Product Development Capacity unless it is required for a particular program, in this way reducing the overall business costs (B) for these products as the market place becomes more competitive over time.

Hence one way to keep the development costs low is to separate this cost from the manufacturing overhead and spread it over more programs. In this way it is possible to increase efficiency.

With more programs, the D development process must be streamlined. Like an assembly line in manufacturing to offset the increased cost of more programs the efficiency must be increased by the increase in volume (i.e. greater utilization of the development capacity itself), where great strides are possible.

As a result of the increase in the number of programs being developed with the same resources, the total cost of each program will be reduced. This is the first Principle of economies of scale, as applied to Product Development. This has added side benefits, based on the increase in capability of the developer from the increase in learning cycles or experience in this particular type of Product.

It follows that the number of programs that can be developed could be greater, if an independent Product Development capacity were available that was not constrained by the manufacturing capacity of any single manufacturing plant. In addition to this, there is a added benefit that with the constant force of change a company not linked directly to a particular manufacturing process, will be more flexible to move in the direction of new innovations if (more accurately WHEN, not IF) the technology changes again.

To offset the increase of F from a greater number of programs, all efforts must be made to utilize common or family tools and flexible equipment. Even the elimination of process steps, which require capital investment, must be avoided by design of the product, even if it increases the unit costs. In general, all manufacturing processes may need to be modified to suit this effort to increase flexibility and capacity utilization. We are now forcing change to serve the market instead of reacting to it.

4.5 Manufacturing capacity and LVP

One of the key tactics used to reduce risk in the manufacturing process for HVP was to have dedicated manufacturing cells with little or no changeover of product. This allowed for limited inefficiencies at high volume and lower risk processes (i.e. welded parts directly after molding to reduce issues from warp...etc).

So, based on these factors, it is clear why the major companies in today’s market are uninterested in this LVP market. It seems clear that a new source of capacity is needed, but one that does not require significant increases in
investment because the volumes being low would not justify this.

To accomplish this, it was necessary to challenge a few paradigms of the current manufacturing process described above. First, dedicated processes linked in series in a dedicated manufacturing cell did not allow for the flexibility required. This was the only acceptable process 10 years ago when we started to break this trend and it was strongly resisted by all as too risky (particularly from the suppliers of the capital equipment because this general trend allowed for increased sales of equipment as opposed to better utilization of existing equipment; a common theme throughout the boom years). However, if we recall, the spirit of change is not new for this field as we need only look at the fusible core process and how quickly it has been replaced by shell welded assemblies today.

If we dissect the Shell welding process, it uses a combination a normal molding processes linked to standard vibration welding machines to produce the final part.

The separation of a complex process such as this, into a series of standardized processes, is the key to the transition to LVP.

Therefore, we have two critical aspects to focus on;

Total Product Quality with existing equipment in place at normal injection molders to keep the indirect costs low (S&B) because at lower volumes capacity is more difficult to manage efficiently. The normal injection molders are well suited to this, if the product and process are developed properly as turnkey operations. They are familiar with processes such as these and, in many cases, the capacity required for LVP is possible to fit into unused capacity available at these companies, in addition to being available in local markets near the OEM.

In addition to the molding process changes, the assembly processes need to be developed that can be placed at or near either the OEM or the molding facilities. However, since this equipment cost is much lower and it is more flexible in general (depending on the actual design of the equipment) than the molding equipment it is much more possible to do this. Actually, a smaller, more flexible process for welding an assembly can be set up in a location that best suits efficiency and utilization of that capital. In fact, this has already been done in a number of locations around the globe today and the fear of molding and welding in different facilities has been accomplished in multiple facilities by MPI and others, for over 10 years.

Not to state that this is easy, but it is possible. It is required that the design of the molded parts/weld joints and related features should be optimized for this kind of process. All efforts must be on building controls that allow for more variation in the welding process, while reducing variation of the molded parts. This can only be accomplished with a new Product Development Process.

4.6 The LVP process, a Lean Product Development Process

The Product development process we call LVP is essentially the same as the normal product development process with a few major changes. The first is based on Time. As stated above, in HVP, total time is dependent upon the overall schedule established by the OEM and, therefore, it was not a significant variable for our consideration then. However, for LVP the opposite is true. This is partly due to the fact that these programs are not typically part of a major project and, more importantly, because time is directly proportional to the development cost (D). Therefore, the longer it takes, the more it costs and there are diminishing returns when we look at the relationship of time to Total Product Quality and we see that time (T) is directly proportional to development cost (D) and both are inversely proportional to Total Product Value. Therefore, Time is essential for LVP. It is commonly stated that “time is money” in this case that is literally true. Therefore, we need to look at every aspect of our process in the same way we look at an assembly line. We must balance capacity in each operation, from design to analysis to test and so on.

To accomplish this, it is critical to have complete and clear program requirements at the start of a program and efficient program management tools. The more time spent here the better. Most causes change in any program is due to a lack of information pertaining to requirements at the start of a program. In the LVP process, the more loops in the process the higher the cost of D. Therefore, we need to limit these loops and, in doing so, we must rely upon our experience over many programs to determine the proper design for the specific application and requirements. This is managed by the use of a standardized design process where all designs are created utilizing common methods to allow multiple engineers to work on the design at the same time, thereby, reducing the time to develop and increasing the amount of cross evaluation during the design process. Furthermore, it is critical to remove steps in the development process itself by effective utilization analytical tools such as FEA, CFD, Engine simulation, mold flow, and standardized design practices. We can almost entirely remove the prototype phase of a normal program as the costs for this step in the development process is significant. On most LVP programs, we go directly from the concept phase to the production phase eliminating the need for prototype tooling, parts and testing. From the initial concept, we evaluate the manufacturing requirements, functional requirements, and quality requirements utilizing...
analytical tools to assess the risk of the concept, while simultaneously verifying the performance and fit with rapid prototype parts from the concept phase. In effect, the use of virtual testing affords us great savings in development cost and time. Again, this is also enhanced by the experience gained from the increased number of programs being developed as a result of LVP.

LVP Development Process

![LVP Development Process Diagram]

Now that we have addressed the system differences from a normal HVP program, there are many subtle changes in the design process itself that are required to get every aspect of the process streamlined to allow for maximum efficiency at Low volumes. In effect, the factors that are important for LVP are sometimes not obvious and require a great deal of cost analysis to determine. It is critical to approach every decision with an open mind and an understanding of the Total value formula above. For this, the engineers require a tool that is used constantly to see the optimum choice in every case.

First and foremost, we need to look for tradeoffs between F & D vs. P & I. To accomplish this, we may need to add features considered unacceptable at high volumes, such as the use of added parts that are common across programs reducing tooling cost of each program and also development cost/time. For example, the use of bolt-on vacuum fittings that may be easily molded in high volume tools with added tooling cost, but are very inexpensive purchased in bulk from inexpensive tooling and using manual operations to assemble them, allow for a great deal of diversity from simple standard parts to make many more programs cost effective vs. the added tool cost on every program for that feature (tooling vs. labor cost trade off).

Also, the elimination of brass inserts in favor of self tapping fasteners reduces the equipment cost of the machinery to install the inserts, in addition to, the cost of the insert. In some cases, more complex designed shells will allow for a reduction on the number of shells (tools) required to produce a manifold or, in some cases, the opposite is true and the difference is only known by calculating the two options. At low volumes, the tooling cost is almost always the hardest cost to cover, unless it can be carried over multiple programs leading to significant use of common family tools and interchangeable inserts in tooling to make multiple part numbers with common tooling. In general, the only way to make these choices effectively is to prepare the process prior to completing the concept design in the very first phase. It’s critical to determine the strategy for the lowest cost investment before the design is even started.

Further process changes involve process development plans at the start of the program, from Process flow diagrams to PFMEA’s, to reduce the potential for unexpected process difficulties or added costs after the concept is initiated. In addition, these are required to involve the individual molding sources into the process to make sure overhead and development costs can be minimized or to take advantage of excess capacity on particular machines or equipment, which may not be fully utilized resulting in lower cost.
4.7 Line balancing and Economies of scale

The design process must also be very rigidly planned. Each and every step requires controls to allow for more than one person to work on any task at the same time to increase speed and/or capacity (interchangeability) to insure efficient product development at the fastest speeds; not unlike an assembly line which uses standard processes and interchangeable tooling. For a design process that has very extensive use of the analytical tools, efficiency is also critical.

Use of engine simulation, CFD, and acoustical tuning software to verify the exact configurations of each component and feature of the intake system, from the start of the concept phase and thru any prototype builds or even any changes from production requires the same level of systemization as the design and manufacturing does. In this way, the efficiency of even the analytical work is greater because of the number of programs performed, in addition to, the increased experience resulting from this volume.

Then, use of injection molding software to insure minimal time in part qualification at launch (not to mention tool change costs) and to ensure that prototype tooling can be eliminated. In addition to making design changes at the start to minimize the effects of warpage, prior to building the tool, strategies are developed to deal with any eventual warp problems that may require tooling adjustments, so they can be performed in a steel safe manor. This allows us to avoid typical injection molded tooling debug and process development efforts, eliminating significant cost and time for this phase of the process. The DFP process also allows for the simplest manufacturing process available. This will allow more choices of location to place the molding, thus allowing for sourcing based on capacity availability at the lowest cost and with the lowest overhead, as opposed to, a limited range of choices based on high technical skill. The objective is to limit risk in the design by using standard processes and past experience to avoid unnecessary loops of development.

In this aspect, it is not unlike having specialized players on a sports team. Each player must know and perform his tasks without thinking and in accordance with his team mates and team strategy for any condition in the game. This way he can spend all his time and energy making his skills better at that position by performing his tasks to the best of his ability and in the most efficient way. Instead of trying to determine which task is his and how it affects the others on the team or when it should be done...etc.

The team members in this case are the manufacturing engineers and the development team members with a stake in the success of the program who rely on each player to perform their task on time or the efficiency of the entire group will fail.

4.8 Start with the end in mind.

In addition to using typical DFM techniques throughout the LVP development process, Design for Profit is not just important, it is essential. The main objective for LVP programs is to define the end point first (the Total Product Value, not unlike the examples above for Aluminum intakes (VSI)). Then, construct the program plan and schedule from the end, a target price (or Total Product Value). Finally, calculate the budget and times required for each task and for all the variables in our equation for Product Value (as in section 3.1). This way, we can use these detailed budgets and standardized processes to determine our individual goals at every stage of development or to decide if this program is not viable prior to investing many hours of time into a design that will not be viable no matter what process is used.

![Fig. 4.8.1 The above chart shows an example a Total Cost calculation sheet that is routinely updated with every change and used to meet targets established at program start, for everything from set up times to total development cost](image-url)

To facilitate this, the engineers need a simulation tool that is more like a FMEA that helps to identify risk priority numbers for Total Value. This way, the team can focus more on the important factors affecting total product cost with greater efficiency (i.e. target the highest 1st...etc), thereby, reducing development time while increasing Total Product Value. This is essential because all of the costs are interdependent in the LVP volume range; none can be assumed or overlooked. They all have an effect, and to maintain the efficiency, you must know when you reached a goal. There is no room for exceeding any particular requirement because every aspect of...
Total Product Value is a trade-off. In general, engineers have the most difficulty with this point. Overdesigning any particular feature may reduce the risk of a particular failure, but it could be at the expense of the entire program's viability or if a cost is reduced too much that customer satisfaction may be reduced to the extent that overall volume could be reduced. Therefore, the trade-offs are never simple and all aspects of total cost must be considered.

This is the fundamental difference between LVP vs. HVP Product Development Processes. The differences span from intense use of analytical tools to avoid design iterations to interchangeable process steps which allow for use of unused capacity in the market place, as you would a standard commodity.

From design to launch, the process must be rigidly controlled and subject to a very highly tuned program management process that doesn’t allow requirements to shift or goals to change without adjusting the entire program plan and re-evaluating to the overall goals of the program, Total Product Quality.

5 The Future

5.1 Next steps, future methods, processes and Technology trends

The future is very difficult to predict, but given the flexible and open nature the LVP development process requires, it is more adaptable to future changes in technology, materials, processes and product change.

In this sense, the next steps are not steps at all, in that, the LVP process itself is focused on continual evaluation of the right choices. Considering all variables mentioned above, this process will assist and actually help change progress. Our goal for the future is to utilize this methodology to inspire new process developments and material developments to solve market niche problems. In this sense, we can use a new process or material which has the appropriate characteristics (specifically investment profile) to suit the parameters a particular LVP product would need to be financially viable.

An example of this is our current use of NylonMold for LVP racing manifolds for carbureted engines in the US market (scheduled for launch in 2010 1st quarter) where the volumes are very low, (hundreds per year) and the variations high (5 models to be developed in just the first year). The true goal of the LVP process is to open new markets where none existed before and increase the efficiency of the Product development process to meet the demands of an ever changing market in the 21st century.

6 NylonMold™ - A low pressure casting process

6.1 NylonMold™ providing a solution for LVP and Prototype Phase

NylonMold™ is a very low pressure, gravity-fed, casting process to produce nylon parts (PA6 and PA6 GF30) for LVP or the prototype phase of low to high volume programs. This patented process has been in production for over 10 years for prototype solutions and in the last 5 years being used for low volume production solutions. The proprietary process entails combining an organic compound, caprolactam, with an activator monomer into a dosing unit feeding into the molds with the force of gravity. With the molds heated to a specific temperature, the polymer polyamide-6 (PA6) is produced and solidified in the mold. The resultant material is a production-like material that exhibits roughly 95% the mechanical, thermal, and chemical properties of a high-grade production material used for injection molding processes. This material is far superior to any rapid prototyping material in the world.
This polymerization method is much like the method used for 
production material for injection molding uses without the 
process of pelletizing for re-melting in injection molding 
machines. Therefore, the NylonMold™ resultant material is 
not exposed to these stresses providing a more natural PA6 
material. For prototype phases, using silicone molds is the 
most cost and time effective method to produce complex 
plastic parts for most levels of testing and validation in a 
matter of weeks. As mentioned previously regarding the 
short program timing of a typical LVP project that requires 
your schedule to move from concept phase straight to 
production, NylonMold™ is the perfect solution to bridge the 
short gap from concept to releasing final data for production 
injection mold tooling. The NylonMold™ parts will provide 
the confidence needed to forgo prototype injection mold 
tooling in the development phase. One of the advantages of 
NylonMold™ parts produced in silicone molds is the 
opportunity to produce a part of the design at a very early 
stage in the development process where the CAD models may 
not be in a state suitable for injection molding. This could 
include no draft, thick sections, and/or undercuts. This is 
possible with the flexibility of silicone molds. In addition, the 
NylonMold™ casting is an exothermic process in that the 
material solidifies from the inside out allowing for thick 
sections. These thick sections will not cause shrinkage or sink 
marks in the part.
NylonMold™ as an LVP solution

The NylonMold™ process has now progressed into a viable solution for low volume production. In the LVP process, aluminum molds are used in the same manner as silicone molds for the prototype phase. Due to the low pressure nature of the process, the aluminum molds are minimal in size; basically, the size of the tool is suited to provide an external seal geometry and is typically cored out on the exterior. In addition, the minimum mold size is achievable because there is no need for a cooling circuit as in injection molding.

The LVP process has been successfully initiated on carbureted manifolds projects for the aftermarket performance industry in the United States. The NylonMold™ process is a benefit in that it produced a part with a smoother flow surface to the current production aluminum part and transmits heat through the part more effectively than the aluminum material. In effect, the aftermarket performance industry typically operates its engines at a high rpm, therefore, a manifold running at a cooler temperature will allow for cooler air and higher performance.

6.4 NylonMold™ - A Success and More

NylonMold™ has been a very successful process for MPI for the past 6 years in the many development projects for intake manifolds, cylinder head covers, oil pans, and air induction systems. In several instances, we have utilized NylonMold™ to eliminate the prototype phase of the development, including prototype injection mold tooling, and utilized these parts to validate the design for production. In addition, we have success stories of customers using NylonMold™ parts for extended engine and vehicle durability testing.

Furthermore, the advancement of the NylonMold™ technology into low volume production options has opened the door to many more successes and options to produce a cost effective design, process, and part to meet to once thought to be unattainable cost targets for low volume. LVP has been successful with intake manifolds with plans in process for cylinder head covers, oil pans, and engine front covers. NylonMold™ has lived up to the motto of “Real Parts, Real Fast!” for prototype and now it is now in the low volume production market as a lean process and cost effective option.