

Low-Volume Vehicle Production

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Executive Summary

Many auto companies are targeting low-volume vehicles as a means to increase market share, and in some cases, establish a “halo effect” with niche products. However, there are two critical constraints with low-volume products: engineering and production resource availability, and manufacturing cost. These constraints can be addressed in several ways. Many automotive OEMs have developed relationships with external suppliers to provide engineering and production capacities, while others have focused more on developing internal flexibility. Flexibility can be achieved through flexible manufacturing technologies and product design flexibility (e.g., strategic use of carry-over parts and parametrically designed components). Advanced companies have taken both approaches by developing strategic external partnerships while, at the same time, increasing their own internal flexibility.

The Low-Volume Vehicle Production Project identified technologies, manufacturing processes, and business strategies that enable the manufacture of unique, proactively positioned, low-volume vehicles—at a profit. Lessons learned from this research will be used to educate industry stakeholders and promote effective low-volume vehicle solutions. Further, the purpose of this investigation is to identify and assess strategies and technologies that are supportive of low-volume manufacturing for body-in-white (BIW) fabrication and assembly. The body-in-white (BIW) process presents the biggest manufacturing challenge and opportunity in the development of profitable low-volume vehicle production. This report will not, however, address another critical aspect of low-volume vehicle production—that of product development. While the authors strongly believe that product development is a critical enabler of LVVP, resource constraints require that we focus on manufacturing technologies and strategies.

A review of nameplate sales for 2005 shows that, while the average sales volume for passenger cars sold in the United States is approximately 49,350 units per nameplate, the median is only 24,107. Although the average sales per nameplate for trucks is somewhat higher, 67,090, the data indicates the median is 34,959. Thus, more than half of the nameplates are below the 35,000 unit per year upper limit for this study. And, while CAR can not conclude whether or not many of these vehicles are financially successful at their current sales volumes, CAR is certain that many were not intended to be low-volume vehicles.

It is also certain that low-volume vehicle production will increase in coming years; CAR identified 60 new low-volume products that are likely for North American production from 2006 through 2010. These vehicles include both strongly unique derivatives—for example a different body style (i.e., a CUV compared to a sedan), and derivatives with somewhat less differentiation. This may be a strong indication of manufacturers’ intent to leverage current platforms and assembly facilities in coming years.

The decision to engineer and/or build a vehicle in-house or outsource it to a vehicle integrator is a complex process. CAR has developed a rudimentary decision tree that manufacturers follow to decide whether to make internally or buy externally. This is a critical piece to understand; manufacturers need to compare their strategies against industry benchmarks, evaluate competing technologies and determine viable options. The OEM’s must first decide whether to outsource any part or all of the product engineering. Then, a vehicle manufacturer can proceed down two paths—assembling the vehicle in one of their own facilities or outsourcing the assembly. If the OEM decides on the ‘make’ pathway, they must decide whether or not to build the vehicle integrated into an existing assembly process—sequencing the lower volumes through weld, paint, and final assembly lines—or build a separate line. These decisions are all basic “make or buy” decisions that are a function of availability and cost of required human

skills, physical plant capacity, and (most certainly) tooling and equipment capabilities. A strong understanding of available technologies is a critical element of this decision process.

Another intent of this report is to illustrate manufacturing technology strategies that enable the manufacture of low-volume vehicles. To this end, CAR identified five low-volume vehicle production pathways. The five pathways are:

1. In-house flexible body assembly
2. Integrator-operated flexible body assembly
3. Coach builder
4. Low-cost tooling and assembly
5. Post production vehicle alteration

While each pathway differs from the others in many aspects, there is one common trait—reducing the cost of low-volume vehicle manufacturing. They all also rely on low cost dies and molds, small component runs (often enabled by quick changeover tooling), and cost-effective highly flexible assembly processes (both automated and manual).

CAR investigated a number of manufacturing technologies that are supportive of low-volume production. The list is not—nor could it be—comprehensive. Instead, it is intended to provide an overview of tooling and process developments aimed at reducing the high cost of tooling when manufacturing a low-volume vehicle. It is important to add two caveats. First, it was not the purpose of this report to verify the readiness of these technologies; instead, CAR identified technologies that appear to present opportunity. We make no guarantee as to the accuracy of their performance. Second, CAR made every effort to identify as many low-volume enabling technologies as possible. Although the research identified several potential technologies, it was also apparent that there were other technologies that presented opportunity as well. However, the specifics of many of those technologies were closely guarded, and thus not readily presentable. CAR believes there is opportunity to work with companies providing novel low-volume processes and offer a forum to permit industry to better understand these technologies, while maintaining the privacy deemed necessary.

Low-Volume Vehicle Production

Prologue

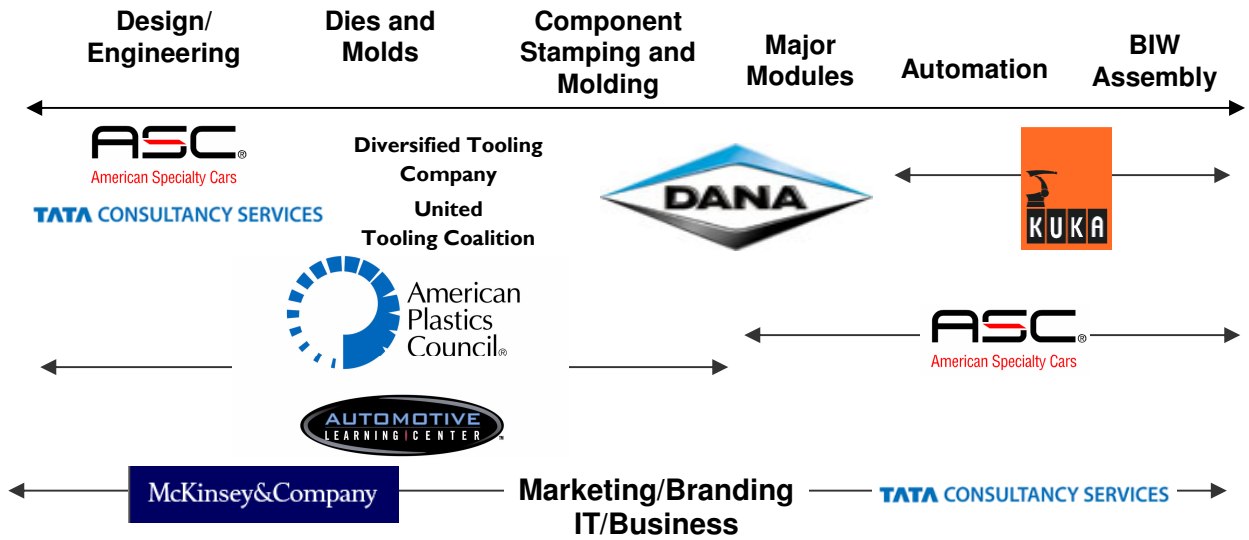
The Center for Automotive Research has been interested in the issues, challenges and opportunities presented by low-volume vehicle production for several years. Phase one of this effort received initial funding from BMW AG. This phase was designed to be a brief investigation of low-volume manufacturing technologies in North America. Phase one was presented to BMW in the first quarter of 2005.

CAR used the Automotive Industry of the Future (AIF), an internal research program funded at CAR by Ernst & Young (E&Y), as the base funding for phase two of the Low-Volume Vehicle Project. The AIF was developed from a grant by E&Y to investigate issues of importance to the automotive industry. Another critical part of phase two was the involvement and support of companies and associations. CAR identified companies and associations that are viewed as industry thought leaders, or had unique knowledge of the low-volume vehicle landscape. The companies that participated in the Low-Volume Vehicle Consortium include:

- American Plastics Council
- ASC, Inc.
- Dana Corporation
- Diversified Tooling Company
- KUKA Flexible Production Systems
- McKinsey Consulting
- TATA Consulting
- United Tooling Coalition

The blend of companies was important to the overall effectiveness of the project. Each company represented an aspect of the LVVP value chain. Figure 1 illustrates how each consortium member filled an important element of that chain. These companies brought a different point of view to the research, and offered insight into their respective areas of expertise.

Figure 1 – Consortium Members



Introduction

Many auto companies are targeting low-volume vehicles as a means to increase market share and, in some cases, to establish a “halo effect” with niche products. Engineering and production resource availability, and manufacturing cost are two critical constraints present in low-volume products. These constraints can be addressed in a variety of ways. Many automotive OEMs have developed relationships with external suppliers to provide engineering and production capacities, while others have placed greater emphasis on developing internal flexibility. Flexibility can be achieved in two main areas: through flexible manufacturing technologies and product design flexibility (e.g., strategic use of carry-over parts and parametrically designed components). The most advanced companies have taken both approaches: developing strategic external partnerships while increasing their own internal flexibility.

The cost constraint is traditionally seen as trading off lower investment costs for higher variable costs. The decision process is driven by volume and financial objectives (e.g., minimizing risk through lower up-front investment). Cost curves for tooling and production automation can differ significantly by volumes, materials, and technologies. Every OEM is attempting to create manufacturing strategies to build low-volume vehicles economically.

The Low-Volume Vehicle Production Project will identify technologies, manufacturing processes and business strategies that enable the manufacture of unique, proactively positioned low-volume vehicles—at a profit. Lessons learned from this research will be used to educate industry stakeholders and promote effective low-volume vehicle solutions. Further, the purpose of this investigation is to identify and assess strategies and technologies that are supportive of low-volume manufacturing for body-in-white (BIW) fabrication and assembly. BIW presents the biggest manufacturing challenge and opportunity in the development of profitable low-volume vehicle production. This report will not, however, address another critical aspect of low-volume vehicle production—product development. While the authors believe that product development is a critical enabler of LVVP, resource constraints require that we focus on manufacturing technologies and strategies.

Section I of this study identifies low-volume strategies and technologies for the manufacture of low-volume vehicles. For this report, low-volume vehicle production is approximately 30 to 120 units per day (approximately 7,000 to 30,000 units per year). The upper boundary was chosen because traditional tooling and manufacturing processes are viable above the 30,000 unit level. Conversely, vehicles manufactured at volumes below 7,000 are most frequently higher priced vehicles, thus enabling handcrafted manufacturing strategies, or the use of high technology solutions.

Section II of the report will investigate strategies and pathways for low-volume production. We will briefly investigate the decision process for low-volume engineering and assembly as well. It is essential to illustrate this decision tree in order to better understand the opportunities and barriers for low-volume vehicle production in North America. We will then address several pathways, including business strategy, part fabrication and assembly that enable low-volume production.

Section III of the report presents four low-volume vehicle case studies. These case studies present opportunity to investigate current strategy, and illustrate techniques that may or may not be effective for low-volume manufacturing. Importantly, it is not our intent to identify successful—or unsuccessful—projects. Instead, the emphasis will be on highlighting elements that we feel provide insight into the challenges and opportunities of low-volume vehicle manufacturing.

Section IV of the report identifies a number of technologies that are supportive of low-volume production. The list is not—nor could it be—comprehensive. Instead, it is intended to provide an overview of tooling and process developments that are aimed at reducing the high cost of tooling when manufacturing a low-volume vehicle. It is important to note that the technologies investigated are, for the most part, tooling-based solutions. (Enabling assembly strategies will be addressed in Section II.) Finally, Section V will provide viable strategies and implementation recommendations to create low-volume vehicles.

I. Strategic Considerations

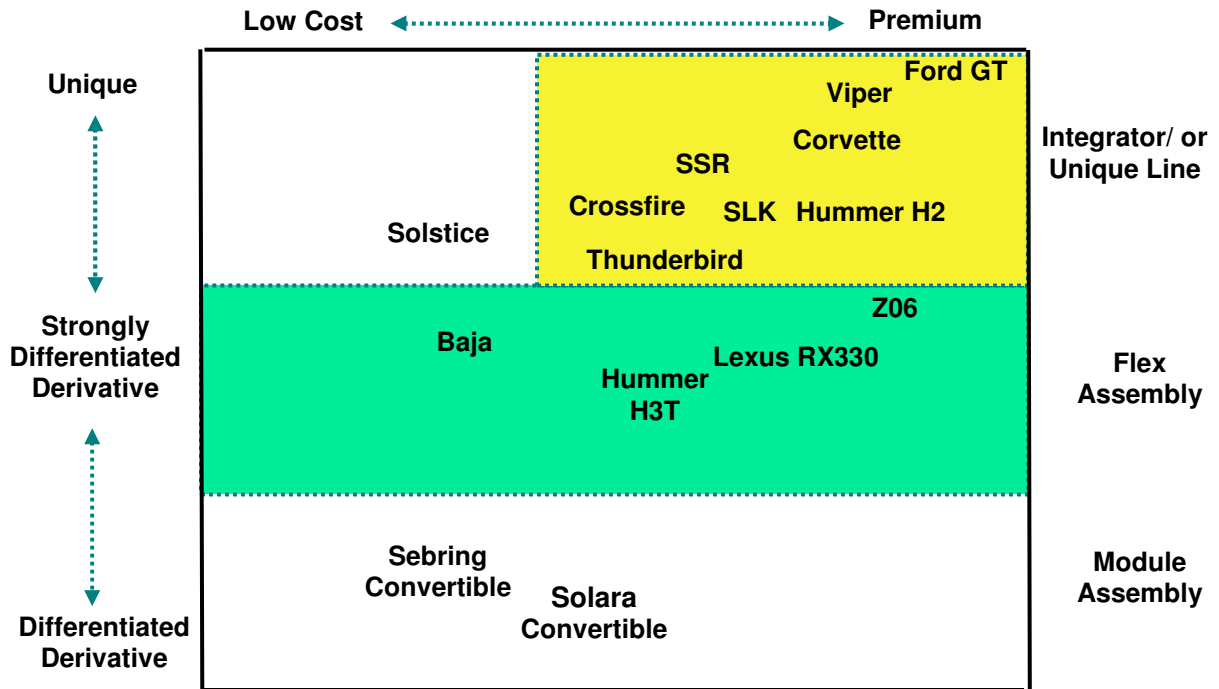
The purpose of this section is to highlight the business strategies that enable low-volume vehicle production technologies. Although the investigation of low cost tooling technologies and processes is an essential part of this study, it is important to first address the differing strategies that enable such technologies. This section will use a decision tree to illustrate the strategic decision alternatives for low-volume vehicle programs. It will then describe the models—or potential pathways—for the manufacture of low-volume vehicles. It is important to note that this project is manufacturing-centric. That is, it focuses mostly on the pathways to manufacture and assemble low-volume vehicles. Thus, it only briefly covers vehicle engineering and program management challenges. By doing so, the authors do not mean to suggest that these issues are not important. To the contrary, they are essential. However, the focus of this investigation is manufacturing opportunities for low-volume vehicle production.

In order to properly frame the discussion of low-volume production, one must first ensure that terminology is concise and clear. For this report, low-volume vehicle manufacturing will include vehicles with an annual production between 7,000 and 30,000 units per year. CAR believes that the definition used for this report presents important challenges and opportunities. The lower end of this range represents mostly high value, luxury vehicles, usually built using higher cost processes. The upper end is comprised of a wide range of products and processes, depending greatly on different vehicle producers' manufacturing strategies. This report will investigate technologies and strategies that may enable the cost effective manufacture of vehicles in this range.

We will consider a range of product strategies to produce low-volume vehicles. Figure 2 shows the level of product differentiation, and sale price. Low-volume vehicles can be grouped into at least three levels of differentiation: 1) Unique platform—a product that is manufactured on a platform that is not shared with other (high volume) vehicles; 2) Strongly differentiated derivative—a product that shares a high-volume platform but is markedly different from the other vehicles on the platform. (An example of this is a cross-utility vehicle built off a platform previously used to build sedans.); 3) Differentiated derivatives—a vehicle that shares a high volume platform, but is differentiated from the other vehicles using the platform. (This could be a sport wagon, or convertible version.) This report will also address a fourth level of differentiation—post production alteration. However, the post production model does not require manufacturing changes, and thus does not appear in the figure. Finally, the right axis includes different manufacturing pathways to manufacture the vehicle.

Figure 2 shows that higher priced low-volume vehicles in North America have traditionally been built on stand-alone assembly lines. These vehicles have often used high-cost manufacturing processes designed for lower-volume, with the higher price of the vehicle able to offset some of the added costs.

Figure 2 – Product Differentiation & Assembly Integration



CAR identified 60 new low-volume products that are likely for North American production from 2006 through 2010 (Table 1). These vehicles include both strongly differentiated derivatives—for example a different body style (i.e., a CUV compared to a sedan)—and derivatives with less differentiation. CAR identified only one possible vehicle with a unique platform. This revelation may be a strong indication of manufacturers’ intent to leverage current platforms and assembly facilities in coming years. It is important to note that CAR has had no direct contact with any manufacturers regarding future vehicle programs. Information on these vehicle programs was gathered through public sources and represents, at best, a highly informed estimate. However, it does give an indication of the intent of manufacturers to further segment their products into smaller niche markets.

Table 1 – Forecasted N. A. Built Low-Volume Vehicle Programs

Strongly Differentiated Derivatives		Derivatives	
Manufacturer	Number of Products	Manufacturer	Number of Products
DCX	5	DCX	6
Ford	0	Ford	8
GM	12	GM	11
Toyota	2	Honda	2
Nissan	1	Subaru	2
BMW	2		
Source CSM, JD Power, CAR Estimates			

A review of nameplate sales for 2005 shows that while the average sales volume for passenger cars sold in the United States is approximately 49,350 units per nameplate, the median is only 24,107 (Table 2). Although the volume per nameplate for trucks is somewhat higher, 67,090 and 34,959 respectively, the data still indicates that more than half of the nameplates are below the 35,000 unit per year upper limit. Importantly, this data must be viewed with some care. First, in any given calendar year, there are vehicles that are either entering or exiting production. Therefore, they may have artificially low sales figures for a given year. Second, we have only looked at sales for the United States market. Some of these vehicles are sold globally; thus this data would be representative of only a portion of the total production volume. However, even given those caveats, it is apparent that the United States market has a large number of low-volume vehicle programs. And, while CAR can not conclude whether or not many of these vehicles are financially successful at their current sales volumes, CAR is certain that many were not intended to be low-volume vehicles.

Table 2 – N. A. Nameplate Sales: 2005 Mean and Median

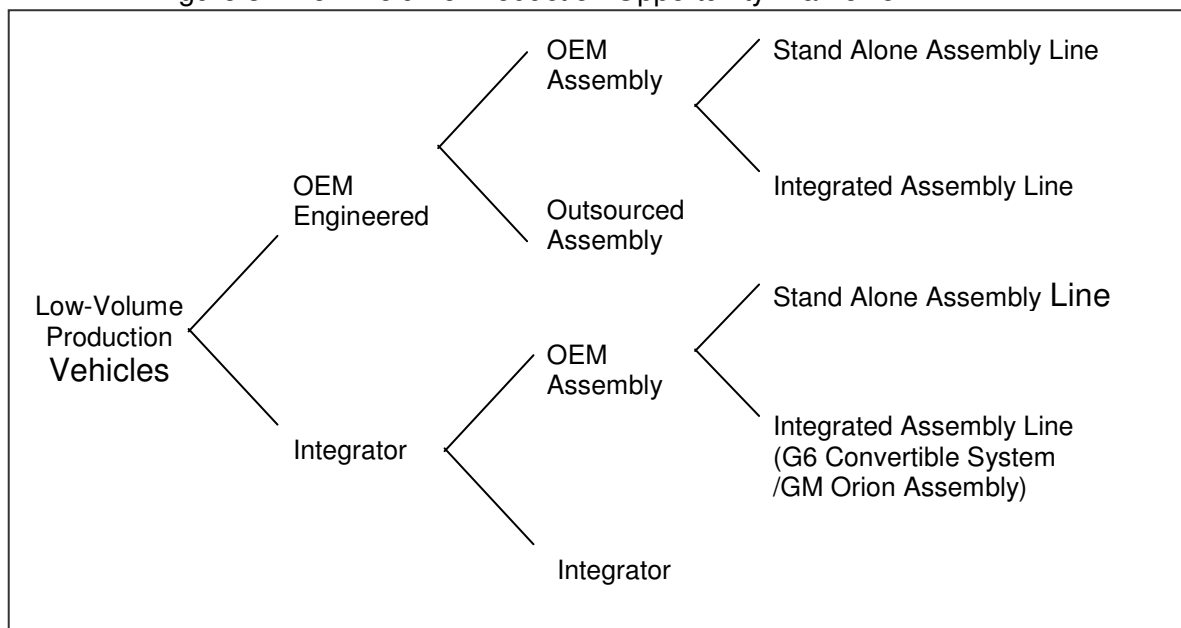
Segment	Sales per Model Year (Units)	
	2005	2004
Passenger Car		
Median	24,107	22,248
Mean	49,350	48,268
Light Truck		
Median	34,959	37,697
Mean	67,090	70,751
Source, J.D. Powers		

II. Low-Volume Opportunity Framework

In recent research, CAR identified what appears to be a 24 month/24,000 unit rule. That is, if a new product is needed in 24 months and not in a manufacturer's current product cycle plan or if the unit production is expected to be less than 24,000 units, it would be extremely beneficial to engage outside engineering and/or assembly resources. While this is not a steadfast rule, it does present a valuable starting point. Given this assumption, it is important to note that the definition of low-volume production used for this study includes both vehicles that would be likely candidates for outsourcing and those that would more likely be built in-house. Therefore, it is valuable to consider the decision process for identifying low-volume product build options, which in turn will provide a foundation for discussion of alternative manufacturing technologies.

CAR has developed a rudimentary decision tree that manufacturers follow to decide whether to make internally or buy externally. This is a critical piece to understand; manufacturers need to compare their strategies against industry benchmarks, evaluate competing technologies, and determine viable options. As illustrated in Figure 1, the OEMs first must decide whether to outsource any or all product engineering. Then, a vehicle manufacturer can proceed down one of two paths: assembling the vehicle in one of their facilities or outsourcing the assembly as well. If the OEM decides to produce the vehicle, they must decide whether or not to build the vehicle integrated into an existing assembly process, sequencing the lower volumes through weld, paint, and final assembly lines or build a separate line. These decisions are all basic "make or buy" decisions that are a function of availability and cost of required human skills, physical plant capacity, and (most certainly) tooling and equipment capabilities. A strong understanding of available technologies is a critical element in this decision process.

Figure 3 – Low-Volume Production Opportunity Framework



European producers have typically used a mix of internal and outsourced engineering programs that have led to both internal and outsourced assembly. In North America, producers have utilized significant engineering outsourcing, and have tended to use internal assembly capacity almost exclusively. For North American manufacturers, low-volume to date, has meant significantly larger volumes than European “niche” volumes, and the domestic manufacturers (with their large installed assembly capacity and declining market share) have ample internal capacity available. This is particularly true since recent union contracts have made assembly labor a fixed cost.

A. Decision Factors for Low-Volume Vehicle Manufacturing

1. Engineering Resource Assignment

There are numerous factors that influence a manufacturer’s decision to engineer a low-volume vehicle internally or conversely, to rely on an integrator for lead engineering. The following is a list of important decision criteria:

- a) Internal and external engineering resource availability and skills: When a manufacturer determines the feasibility of developing a low-volume vehicle, the assessment of potential engineering resources is an initial decision criterion. The decision to engineer internally, or outsource, can in part be viewed as a buy/make decision. It certainly varies among manufacturers, and even from program to program. Some manufacturers have a strong consistent product development process that enables low-volume derivatives. Conversely, other manufacturers struggle with their product development processes. For these companies to develop low-volume vehicles, they must create a ‘skunk works’ team or even outsource vehicle development to a vehicle integrator.
- b) Speed of internal product development: a short development time is arguably a more important competitive attribute for low-volume vehicles than for mainstream products. Low-volume vehicles are often a response to a unique market niche. Therefore, it is critical for these programs to get to market quickly. Thus, manufacturers may look outside of their traditional product development process to meet the time—and cost—constraints required to successfully address the project goals.
 - Subsystem specialist engineering offering opportunity: manufacturers may also look outside for engineering expertise offered by suppliers and integrators. Increasingly, suppliers are capable of full concept development for major vehicle systems. Concomitantly some manufacturers have decreased their engineering resources in efforts to cut costs. The ability to leverage supplier skills for major components may greatly enable the viability of a LVVP. Certainly the most common example of this is the development of convertibles.

- Engineering capabilities complementary to manufacturing services provided by supplier: suppliers with unique manufacturing skills may also present the opportunity to combine engineering with manufacturing expertise. This 'one-stop shopping' can be a strong incentive for manufacturers looking for low-volume vehicle opportunities. The program offers lessons to be learned (material, processing, etc) that can become a competitive advantage: several manufactures use low-volume vehicles to increase knowledge of materials (i.e., aluminum, composites, etc.) or manufacturing processes. Such programs may leverage material or process technology knowledge from suppliers and combine them with internal resources. Often times, these projects are partially subsidized by materials suppliers, making them even more inviting.
- Corporate Pride: several recent low-volume programs have been managed internally to 'prove' that the capability exists within the company. Such a strategy may be important for corporate morale, or executive ego. However, such a project may not necessarily make the best business case for successful low-volume production.

2. Manufacturing Facility Assignment: In-house or Integrator Assembly

The decision to assemble a vehicle in-house, or rely on a vehicle integrator requires numerous inputs. Manufacturers consider plant capacity utilization to be a key element of profitability. To this end, the use of low-volume vehicles is viewed as a means of keeping assembly plants' operations at or near capacity. Currently, labor contracts represent the most critical criteria for domestic manufacturers.

- a) Labor contracts: labor contracts—which for some manufacturers are a fixed cost—present significant incentive to incorporate any low-volume vehicle programs into current assembly facilities. In many cases, the location decision for the manufacture of low-volume vehicles is driven by these long-term contracts. It is likely that labor contracts will continue to be a critical factor for the coming decade.
- b) Manufacturer assembly capacity: manufacturers consider capacity utilization a critical component of profitability. Thus, they are increasingly looking to ensure high internal capacity utilization rates. The addition of low-volume vehicles—especially those leveraging current platforms—into plants running below desired capacity can be an effective tool in maintaining capacity requirements.
- c) Manufacturer assembly flexibility: the ability to introduce low-volume vehicles for manufacture on existing tooling requires highly flexible (body and final) assembly processes. While some manufacturers have had high levels of flexibility for more than a decade, others are just now implementing such strategies. As manufacturers become more adept at flexible manufacturing, the opportunity for internally manufactured low-volume vehicles increases greatly. Conversely, this flexibility may reduce opportunities for integrators.

- d) Integrator assembly capability: the capability of the integrator is critical to any willingness to choose outside assembly. Recent decades have seen limited integrator-run assembly in North America. However, there have been numerous convertible programs that have been successfully operated by integrators. Additionally, there are several European integrators that have demonstrated complete vehicle engineering and production capabilities. While these companies certainly represent manufacturing excellence, their inexperience in the North American market results in uncertainty.
- e) Paint shop flexibility: the paint shop represents an expensive decision point for low-volume vehicle production. Traditionally, paint shops have not been highly flexible. This inflexibility has made adding low-volume vehicle programs a difficult task at many assembly plants. However, newer paint facilities are designed to be capable of handling numerous body styles. Further, due to high investment costs, the paint shop presents an important challenge for vehicle integrators. It may be difficult to cost-justify building a manufacturing plant—and an accompanying paint shop for one low-volume vehicle (e.g., for 10,000 units per year). Instead, an integrator may need several programs before they can justify the expense.

3. Manufacturing Facility Assignment: Integrated or Stand-Alone Assembly

If a decision is made to manufacture a vehicle in-house, the company must then decide whether to build it on an integrated assembly line, or build a stand-alone line. Several recent North American low-volume vehicle programs used in-house stand-alone assembly lines (e.g., Dodge Viper, Plymouth Prowler, and Ford Thunderbird). However, it is likely that as manufacturers increasingly leverage common platforms, there will be fewer programs built off stand-alone assembly lines.

- a) Body shop flexibility: as identified earlier, the flexibility of a body shop is a critical driver in the location decision. The model mix and capacity limitations of a body shop along with expected launch speed (especially with regard to interruption of on-going vehicle mix) are elements of this flexibility. Part and process commonalities are also important criteria. Finally, floor space and inventory requirements present an important hurdle. Many newer body shops are designed to be capable of running several different models, and some are even capable of making different platforms. Yet, it is uncommon to find North American plants running more than three highly differentiated models. There have been suggestions that this is due to the inventory flow issues accompanying numerous variations within the body shop.
- b) Cost of incremental stand-alone assembly: as the cost of implementing a low-volume vehicle into an integrated assembly line decreases, it becomes less likely that manufacturers will use in-house stand-alone assembly lines. It is possible that only high-end halo vehicles built off unique platforms will be considered for stand-alone assembly in the future.

- c) Cost of incremental stand-alone paint shops: the paint shops have historically presented a challenge for LVVP. Although paint shops have become more flexible in recent years, they continue to present a significant cost. Due to emissions equipment (among other costs) it can be difficult to justify the paint shop for a stand-alone assembly line (either in-house or integrator-operated).

III. Low-Volume Vehicle Manufacturing Pathways

An important aspect of this report is to illustrate manufacturing technology strategies that enable the manufacture of low-volume vehicles. To this end, CAR identified five low-volume vehicle production pathways. The five pathways are:

1. In-house flexible body assembly
2. Integrator-operated flexible body assembly
3. Coachbuilder
4. Low-cost tooling and assembly
5. Post-production vehicle alteration

While each of these pathways differ in many aspects, all can be capable of reducing the cost of LVVP. These strategies also rely on low-cost dies and molds, small component runs (often enabled by quick changeover tooling), and cost-effective, highly flexible assembly processes (both automated and manual).

The role of vehicle integrators is a central point for any discussion of low-volume vehicle production. CAR identified three pathways for integrators to manufacture vehicles (Integrator-operated flexible body assembly, coachbuilder, and low-cost tooling and assembly). The coachbuilder pathway also presents a proxy for the OEM-operated stand-alone assembly facility.

Finally, CAR includes the post-production vehicle alteration model as an alternative to the other, more investment-intensive, pathways. This model leverages the strong aftermarket segment of the industry to quickly deliver unique vehicles (albeit with far less differentiation). While it may not be viewed by many as a new—or ‘unique’—vehicle, it does offer two important opportunities. First, as stated earlier, it presents the opportunity to create somewhat differentiated vehicles very quickly. Second, it creates a pathway to prove developmental manufacturing technologies.

A. In-house Flexible Body Assembly

Unlike many North American OEMs, the Asian manufacturers have had a tendency to keep product development and manufacturing internal (in most cases¹). The Asian model is built on standardized product and process development, which they believe will be compromised by relying on outside vendors. Asian manufacturing facilities have been developed to be flexible within the constraints of each company’s product envelope. Toyota, Honda and Nissan, for example, have very well defined and coordinated product and process strategies. To further increase flexibility (and the ability to produce small lot production), the number of platforms is decreasing without a corresponding decrease in nameplates. Nissan, for example, announced a reduction of over 50 percent in the number of platforms: from 26 in 1999 to 12 in 2007, along with a total vehicle production increase of over 12 percent from 2003 to 2005.

¹ Some Asian manufacturers have historically used keiretsu partners to produce vehicles.

The Japanese market includes numerous models that are manufactured at volumes below 35,000. However, a majority of these vehicles share platforms and would not be considered substantially different for this project. Table 3 shows selected low-volume Japanese-market vehicles that are unique—or substantially different from other products. The majority of these vehicles are either luxury or performance roadsters. We have also included two low-volume body-on-frame trucks (the Toyota Land Cruiser and LX). For illustration purposes, CAR has included one higher volume platform (Toyota NBC-1). The NBC-1 shows Toyota’s ability to manufacture a large number of highly differentiated low-volume vehicles from a single platform. It is important to note that the many variations are built at several plants in the Toyota system.

Table 3 – Low-Volume Japan Vehicle Production

Manufacturer	Nameplate	Platform	Plant	Source Country	Car/Truck	CY2004
Ford (Mazda)	Roadster	J07	Ujina (U)	Japan	Car	25,144
Honda	S2000	SSM	Suzuka J-Line	Japan	Car	6,954
Renault/Nissan	Fairlady Roadster Z	FR-L	Tochigi	Japan	Car	11,882
Renault/Nissan	FX35/FX45	FR-L	Nissan Shatai	Japan	Truck	36,426
Renault/Nissan	Fairlady Z	FR-L	Tochigi	Japan	Car	23,578
Toyota	IS	620N/740N	Tahara	Japan	Car	0
Toyota	LS	LS	Tahara	Japan	Car	37,904
Toyota	SC	MA	Kanto Higashi Fuji	Japan	Car	10,827
Toyota	ist	NBC-1	Takaoka	Japan	Car	0
Toyota	Succeed	NBC-1	Kyoto	Japan	Car	23,966
Toyota	Raum	NBC-1	Central Automotive	Japan	Car	40,050
Toyota	xA	NBC-1	Takaoka	Japan	Car	29,836
Toyota	bB	NBC-1	Central Automotive	Japan	Car	11,273
Toyota	bB	NBC-1	Takaoka	Japan	Car	26,938
Toyota	Boon	NBC-1	Ikeda #2	Japan	Car	13,884
Toyota	Land Cruiser 70	NU/029N/152N	Yoshiwara	Japan	Truck	31,040
Toyota	LX	NU/029N/152N	Yoshiwara	Japan	Truck	10,863

Source: CSM Worldwide, others

The manufacturing strategies of the assemblers are probably the most important determinant of the tooling and equipment selected for low-volume production. CAR believes that how manufacturers develop their high-volume production strategies directly determines the viable methods (including processes, tooling and assembly techniques) used for low-volume production. Some manufacturers have chosen to invest in highly flexible production equipment, while others have decided to invest in less flexible strategies. Those that have highly flexible assembly strategies are more likely to incorporate a low-volume product into their existing facilities, and therefore may have very different technical solutions than those companies that have traditionally pursued a dedicated (less flexible) approach.

It is likely that at the upper range of low-volume production (20,000 to 30,000 vehicles per year), many of the more flexible companies can incorporate such niche vehicles into their current assembly paradigm using methods common to their higher volume vehicles. Those programs at the lower end of the range (approximately 10,000 units) are less likely to be incorporated into the current plants of either the flexible or more limited producers. Programs in the lower range likely require unique solutions and offer opportunity for novel technical applications. Therefore, as we consider new technologies, it is important to ask how, or if, this technology fits into the current manufacturing paradigm.

Different strategies are seen across Original Equipment Manufacturers (OEMs) regarding flexibility and low-volume vehicles. These strategies play a vital role in each company's approach to low-volume production, and give a better understanding of the tools each company uses to successfully deliver low-volume vehicles.

1. Asian Strategies

Asian companies have generally taken the approach of increasing internal high-volume flexibility and making many derivative vehicles from a common platform. In contrast, the North American approach, though headed in a similar direction, relies more on outside support for small volume production. Internal plants are becoming more flexible through product and process standardization, but are not designed for the low-volume nameplates often seen in Japan.

The Asian auto companies (e.g., Toyota, Honda, and Nissan) have had a long-standing strategy of standardized product and process design and production flexibility as a key component of their low-volume strategy. Many body types are derivatives of other types, often encompassing a significant amount of carry-over components (such as underbody and engine compartment). Derivative bodies typically have similar geometric envelopes (i.e., the body fits within the operating window of the automation process) and are compatible with a flexible manufacturing process. Generally, companies are reducing the number of platforms because of cost, while trying to maximize the number of body styles/variants from each platform. Reducing the number of platforms reduces development costs, allows for more component carry-over between models, and standardizes product design in support of manufacturing flexibility. All automakers achieve body assembly flexibility through programmable automation (robots). Uniquely different vehicles at low-volume (under 50,000 annual units), however, are often a different story. A brief description of the flexibility approach of major auto companies is presented below.

a) Toyota

The Toyota body manufacturing strategy is based on body shop standardization and (consequently) product design standardization. The Flexible Body Line (FBL) was first introduced in 1985 at 17 plants around

the world. In addition to model mix flexibility, new product launch times were reduced to nearly zero losses. (The primary FBL objectives were flexibility, lean and quick launch). The FBL was not designed to accommodate low-volume production. As Toyota added FBL lines, their model mix capability increased (from over two per body shop to over three per body shop, on the average). But in general, the FBL was designed for large-volume product mix with a capacity of over 20,000 units per month. The FBL is very effective for low-volume vehicle derivatives (such as 4WD, lift back, sedan/coupe versions of related vehicle platforms on the same body line.) Derivatives can be competitively produced in volumes of a couple of thousand units per month. FBL characteristics include:

- They use a multi-tooling approach with many pallets (underbody, two body sides, engine compartment, and RCU – roof/cowl/upper cross member). The pallets come together to make the framing station (Figure 4).
- Most OEMs refrain from the multi-tooling concept because of quality problems from dimensional variation, but Toyota has managed the process effectively (Figure 5).
- Several thousand combinations of pallets are feasible.
- Flexibility can be achieved by changing the mix of pallets in the body shop.
- Volvo (Gothenburg, Sweden) has implemented a body shop based on Toyota's FBL and has achieved many of the benefits touted by Toyota.

Figure 4 – Intelligent Flexible Body Line Pallet

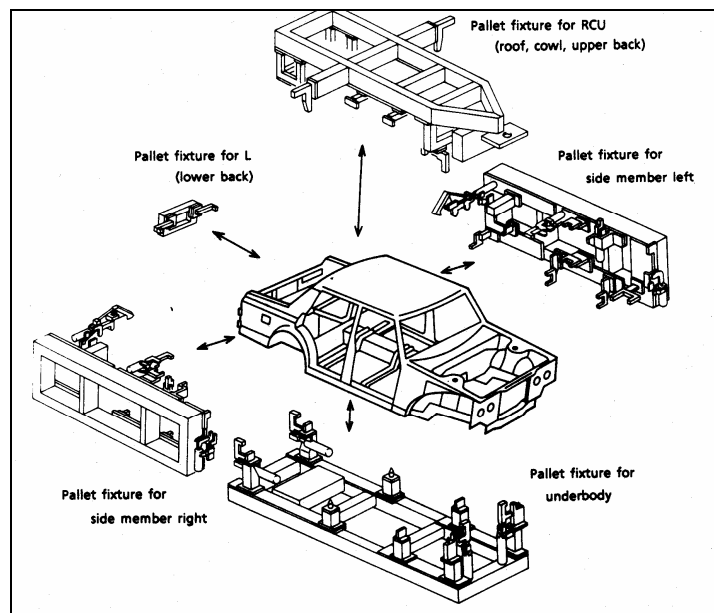
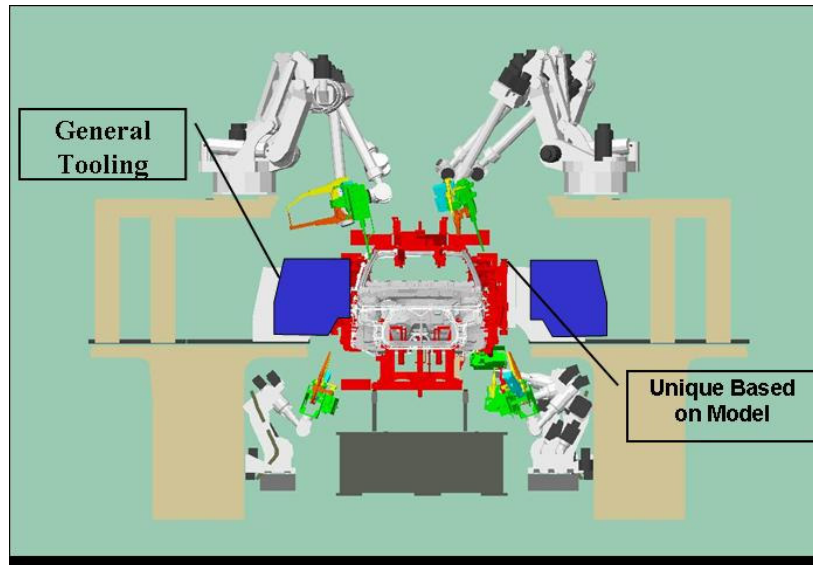


Figure 5 – Flexible Body Line Framing



In 1998, Toyota changed from the FBL to the Global Body Line (GBL) for body assembly, with several objectives in mind. Pallet simplification (reduction in pallet count) and improved flexibility and maintenance were achieved. An innovative approach to framing the body from the “inside out” was developed, and an overall higher level of programmable automation encompassed over the FBL system. The GBL is more accommodating to lower volumes than the FBL, but is targeted toward handling a model mix (up to eight) of derivative body styles.

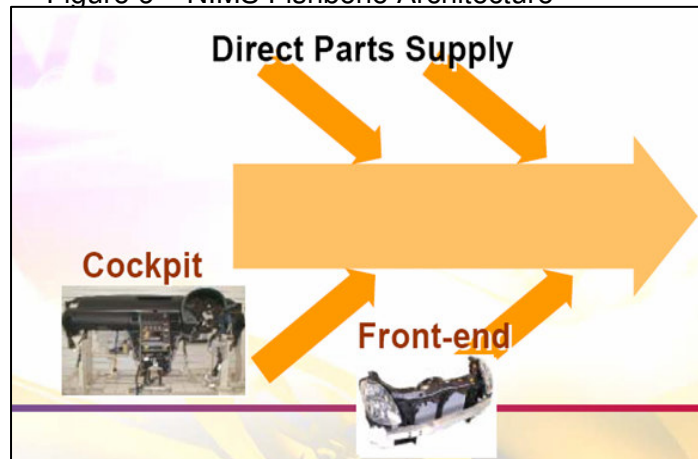
b) Nissan

The Nissan flexible assembly technology is called IBAS for the Intelligent Body Assembly System. This system, first introduced in Tochigi in 1989, replaced rigid jigs and fixtures with numerically controlled robotic locators. The initial span of IBAS included a provisional assembly station for the major body subassemblies (underbody, body sides, roof, etc.), a gauging and welding station (framing), and a body accuracy measuring station. These three stations could accommodate totally different body variants, but the upstream subassembly processes were conventional with dedicated hard fixtures. The second generation IBAS system was introduced in Kyushu in 1992. This body shop eventually added upstream IBAS technology for the engine compartment and body sides. Although flexible (able to accommodate up to eight different body styles on the same line), the system’s complexity has been an ongoing concern.

More recently (approximately 2000/2001), International Truck purchased IBAS technology for their Ohio (United States) truck plant to make large truck cabs. IBAS was re-designed and installed by Nissan to construct five different truck cab models at the International plant.

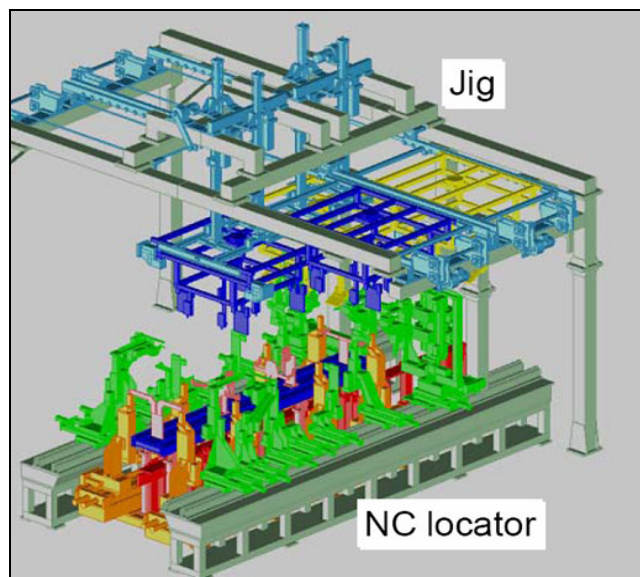
IBAS has since evolved into the major tooling component of the “Nissan Integrated Manufacturing System” or NIMS (Figure 6). NIMS is a flexible single body line with integrated fishbone lines; often providing modules produced on or off-site to the single body line. The major assembly stations (e.g., framing) still employ the basic IBAS technology with flexible NC locators (Figure 7). The NIMS system is producing eight body styles on four vehicle platforms at the new state-of-the-art Mississippi (United States) plant; with some vehicle volumes as low as 10,000 per year. Nissan has indicated that this system can be competitive with model variants as low as 1,000 per year.

Figure 6 – NIMS Fishbone Architecture



Nissan’s flexible tooling can introduce new models 50 percent faster at 50 percent lower tooling investment cost than non-flexible tooling.

Figure 7 – Nissan Flexible Body Assembly Tooling



c) Honda

The Honda body assembly process is standardized worldwide. Local refinements are made for labor and automation tradeoffs due to labor costs and production levels. The Honda process, like many other Japanese processes, is based largely on product and process standardization, and programmable automation. Process standardization in the body shop is a large factor in Honda's strategy to launch plants with the same vehicles, nearly simultaneously. In many instances, this is accomplished over a weekend with minimal loss of production.

Through programmable automation, Honda's strategy is to eliminate (or at least minimize) model-specific jigs that inhibit flexibility. Geometric locators are integral to robotic automation so that robots can fulfill dimensional locating roles in addition to welding. This approach is made possible through "high accuracy" robots that were developed internally at Honda. Commercially available robots have also been incorporated from suppliers like Yaskawa Electric and Fanuc. The processing often has robots holding parts geometrically (with locators) and moving the parts under fixed welding stations (e.g., pedestal welders), resulting in a more precise spot weld location (Figure 8). Servo-welders also contribute to welding accuracy.

The general body shop layout has two major lines, underbody build-up (Figure 9) and structural framing, with smaller feeder lines for different subassemblies. Honda touts the significant advantage of a 40 percent engineering and tooling investment savings through the New Honda manufacturing process.

Figure 8 – Honda Robotic Fixturing Technology



Figure 9 – Honda Underbody Re-spot Line



2. North American Strategies

While the Japanese OEM leaders began aggressively pursuing flexibility in the early 1990s, Ford and GM efforts began in earnest more recently. In most cases, flexible technologies are initially introduced at a cost premium, so business and marketing strategies probably account for the timing differences.

(Note: Toyota, Honda and Nissan would now indicate that their flexible assembly systems cost less than traditional rigid systems when looked at from a company-wide perspective. In some ways, the myth that good quality costs more than bad quality is analogous to flexibility costing more than non-flexible systems: once you achieve it, it costs less.)

a) General Motors

The Ford and GM approach to flexibility is similar and relies significantly on supplier coordination. The new Ford/GM flexible facilities rely on close proximity to outside suppliers and extensive use of modularization (examples include the Chicago and Rouge plants at Ford, and the Lansing Grand River plant at GM). Their push toward flexibility began later than most Asian companies with the primary goal of more rapid vehicle launches and a broader product mix at any one plant (to support lower volumes of any one vehicle). The Ford Rouge plant, for example, has the capability to interchange three vehicle platforms, producing nine different models. Standardized manufacturing modules (“plug and play”)

are a key aspect of Ford's and GM's strategy. Both companies like to employ proven, off-the-shelf manufacturing components and supplement them with standardized processes and layouts.

GM has three key elements as part of their flexibility strategy: common vehicle architecture and manufacturing systems, robotic welding, and early simultaneous engineering with both product and manufacturing engineers. The success of this strategy requires a "common" standardized approach to product and process design. For example, common locator points are assigned when possible. As much of the vehicle is designed using common architecture as possible, and then unique portions are assembled off-line, or by a supplier. To enhance manufacturing flexibility, GM has taken a further step with the introduction of C-Flex (Figure 10). C-Flex replaces body-specific tooling for welding sub-assemblies. Multiple variations of assemblies such as floor pans, deck lids, hoods and engine compartments can be welded using the same set of tools and robots, simply by reprogramming the tool. C-Flex is a servo-driven, programmable tooling system that can adjust to the contours and size of various automotive models and body components. GM president, Gary Cowger says that introducing a new model like the SRX would normally cost \$150 million, and the SRX was brought on line for about \$30 million (the SRX is on a common platform). C-Flex is provided by Fanuc Robotics, Rochester Hills, Michigan.

Figure 10 – General Motors C-Flex Technology



b) Ford

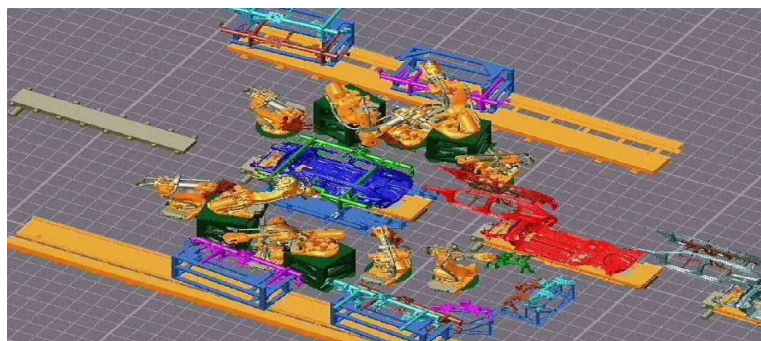
Ford's strategy for flexible, low-volume body shops focuses on process standardization. Flexibility and lower investment costs are achieved by having standardized process cells built from commercially available components. The design of these process cells for producing sub-

assembly modules can be chosen in appropriate quantity and configurations. Ford indicated that they will use approximately 300 standardized components (robots, material handling, weld guns, etc.) to design sixteen modular cells. Programmable automation and advanced technologies are a critical part of the standardized components. Advanced technologies, such as laser welding, in-line coordinate measuring machines, and robots are key aspects in achieving flexibility. This standardized process strategy is intended to result in flexibility sufficient to handle eight models from two different platforms in a single body shop. Ford projects that 75% of their body shops will adhere to this design by 2010, as each new body shop is fitted with this approach when new models are introduced.

c) Chrysler Group

DaimlerChrysler's strategy for body shop flexibility focuses on commercially-available robots. This strategy relies extensively on development collaboration with outside robotic suppliers such as ABB and Fanuc, and systems integrators such as Comau-Pico and Kuka. DaimlerChrysler cited the significant advances made in robotic performance for accuracy and payload capability, as they experience major price reductions. DaimlerChrysler will use the "free market" with competition to contain development costs. The cost for extremely capable robots today is roughly one-half the price of just a few years ago, and this trend is expected to continue. DaimlerChrysler indicated that today's accurate robots are easily capable of handling geometric tooling as end-effectors, even on critical assemblies. While this strategy has been used by companies for several years, the robotic accuracy and repeatability today is adequate for much, if not all, of the body. Similar to Ford and GM, DaimlerChrysler will upgrade their new plants with this technology as they introduce model changeover and will evolve this technology over time as the marketplace continues to make advances. (This approach of upgrading over time based on the current technology is slightly different from some of the Japanese strategies that attempt to standardize all plants to approximately the same generation of technology. There are merits to both approaches.)

Figure 11 – DaimlerChrysler Flexible Robotic System



3. European Strategies

a) Renault

Renault has a sophisticated product and process strategy for flexible body manufacturing. The product strategy focuses on standardizing body variations around three factors: body style, wheelbase and overhang. Each of these attributes has constraints that must be met in order for a body to be produced on the standardized manufacturing process. The body shop relies on robots to carry and locate geometry tooling (very similar to the DaimlerChrysler strategy). Both DaimlerChrysler and Renault attribute the success of the robotized body shop to the increased accuracy and payload capacity (to carry geometry tooling) of today's robots. The Renault body shop has no static tooling. All tooling is "load and place" with robots, and therefore, is programmable. Renault goes a step further than programmable part locators by incorporating geometry pallets as the major mechanism for material handling. The geometry pallets, similar to Toyota's, have unique body tools on each pallet for a particular vehicle model. Model mix can be affected by altering the model mix of geometry pallets. The framing station, called the "Flex-Framer," has the pallet holding the underbody and engine compartment, as robots pick up model-specific tooling to locate various assemblies and members to add to the body-in-white. Renault has also standardized the vehicle build by requiring that all models have to be built up in a progressive assembly line sequence. This build is inclusive of the underbody, engine compartment, body sides and roof (standard assembly sequence), that is somewhat dictated by the geometry pallet concept.

Figure 12 – Renault Flexible Robotic Workstation

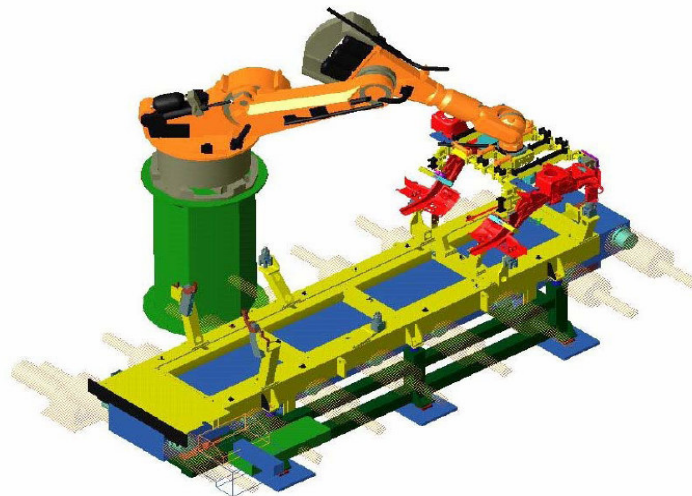


Figure 13 – Renault Flexible Robotic Body Framing Cell



b) BMW/Audi

In general, the BMW and Audi philosophies for body building are similar for low-volume and high-volume vehicles. There is little distinction between high- and low-volume lines, except in regard to the degree of automation and line speed. This strategy is driven by the priority given to quality and design flexibility. All the flexible processes described earlier have inherent product design limitations. Common locating holes, wheelbase size, and outside body dimensions are examples of engineering elements that limit design flexibility. The German companies indicated that they do not wish to be constrained by a design envelope. (It was interesting that BMW was content to have numerous late engineering changes in program development if it contributed to having state-of-the-art product and process technologies.) Furthermore, their high-volume manufacturing processes (predominately dedicated body lines) are designed to achieve a high level of quality, and they are concerned that flexible lines will compromise the standard process and their ability to introduce new technologies as they become available. Although inherently more expensive, this strategy for quality and product performance overrides the cost benefit of flexibility. In order to help contain high costs (especially high investment costs with low-volumes) and meet their quality requirements, they place significant emphasis on staying at the technological cutting edge. They are technology leaders at introducing new body technologies. Some current examples of advanced technologies include: laser welding, weld-bond adhesive, hydroforming tubes, advanced high-strength steels and aluminum assemblies (axle assemblies, body structures, etc.).

B. Integrator Operated Flexible Body Assembly

The role of vehicle integrator is a central point for any discussion of low-volume vehicle production. CAR modeled the integrator operated flexible body assembly pathway on two current production operations. These two facilities offer examples of differing technology approaches. One approach encompasses the body shop, final assembly and paint shop; the other is designed to include only the body shop while another supplier operates the paint shop and the manufacturer controls the final assembly. It is important to note that the second model could easily become part of a complete integrator-operated manufacturing strategy.

The human resource (HR) management systems observed at the independent assemblers (ASC, Karmann and Magna-Steyr) played a key role in their ability to produce cost-effective vehicles. Although the focus of this project was on technical strategies, it was clear that flexible HR systems were necessary for the effective operation of the low-volume body shops and the effective use of flexible automation—whether it be automated or manual. Tooling varied, from simple hand-assisted weld guns to robotic welders and indexing fixtures, depending on the volumes (and cycle times) at each shop. Operators were trained and relied upon to handle as many as six different job assignments at several plant locations. There were sophisticated training programs and job rotation that enabled operators to retain adequate skills for any of six different assignments that they might be directed to on a given day. Also, with longer cycle times (five to seven minutes versus about one minute in a high-volume plant) the number of tasks performed per cycle is far greater in a low-volume facility. One company that managed multiple low-volume vehicle lines (plants) indicated the need to shift employees between plants when volume ceased or shifted between lines, and employees were expected to pick up new responsibilities almost immediately. The importance of flexible HR systems for low-volume production cannot be over-stated, and should be an important consideration when evaluating alternative production technologies.

The ability for an integrator to manufacture several vehicles at one location, using a common body shop and common assembly line is a model of great interest—especially for vehicle integrators. However, in North America, high investment costs present a chicken and egg dilemma. Several integrators have shown the desire—and even capability—to create low-volume vehicle manufacturing facilities in this market. However, it is likely that the investment required for a multi-vehicle plant suggests a commitment for more than one vehicle program. Manufacturers on the other hand have shown great hesitancy to make such a commitment. The recent trend has been for manufacturers to pull outsourced vehicle manufacturing back in-house to take advantage of available internal capacity.

The Chrysler Toledo Assembly Plant is certainly of interest because of the high level of supplier integration, but the size capacity of the facility is also intriguing. The 135,000 (estimated) capacity of the plant is significantly smaller than most new manufacturer-operated facilities. This suggests that lower scale economies

(traditionally associated with body shops) may be economically achievable. It further reinforces the idea that an integrator-run niche plant capable of running three to five different low-volume products may present a viable strategy for North America.

The new Toledo plant represents the highest degree of supplier integration in any major assembly facility in North America. The paint shop, chassis assembly and body shop are owned and operated by suppliers, while final assembly is owned and operated by DaimlerChrysler. This model offers a beginning point for the integrator-operated model.

The capacity of the new Chrysler facility is approximately 135,000 units per year, with the capability of manufacturing up to three unique products simultaneously. The body shop is expected to run one high-volume vehicle (Jeep Wrangler) with the option to introduce another production vehicle, and allowing the build of a pilot model.

To accomplish this feat, the body shop system was created using highly flexible robotic cells. The following describes the technology Kuka implemented in the new Toledo facility. Importantly, it is similar to a discussion presented earlier regarding in-house flexible assembly—Kuka robots are used by several manufacturers for their internal strategies.

In the Kuka body shop, the ladder system is a robotic transfer system that utilizes separate static geometry fixtures: one for the current product, the other as protected space for the future model that is in reach of existing robots. The ladder marriage tool is protected to add a tool tray slide for the future model.

The front and rear floor pan system employs a robotic transfer system that utilizes separate static geometry fixtures—one for the current product, the other as protected space for the future model that is in reach of existing robots. The ladder-pan marriage system is a seven axis robotic transfer system that utilizes separate static geometry fixtures—one for the current product, the other as protected space for the future model. Welding robots are positioned in such a way that they can be used for both the current and future models, with the protected space for additional robots on the opposite side of the tool.

The under body is a skid on a roller conveyor system that will utilize generic skids for current and future models to transfer the vehicle from station to station. Fixturing for the current model is by static fixturing, while the future gaging will occur with dump-in locators. Component fixturing is by geometry docking end effectors to provide flexibility for the future models. The Body Side System is also a 7th axis robotic transfer system that utilizes separate static geometry fixtures—one for the current product, the other as protected space for the future model. Welding robots are also shared between models by utilizing a 7th axis slide.

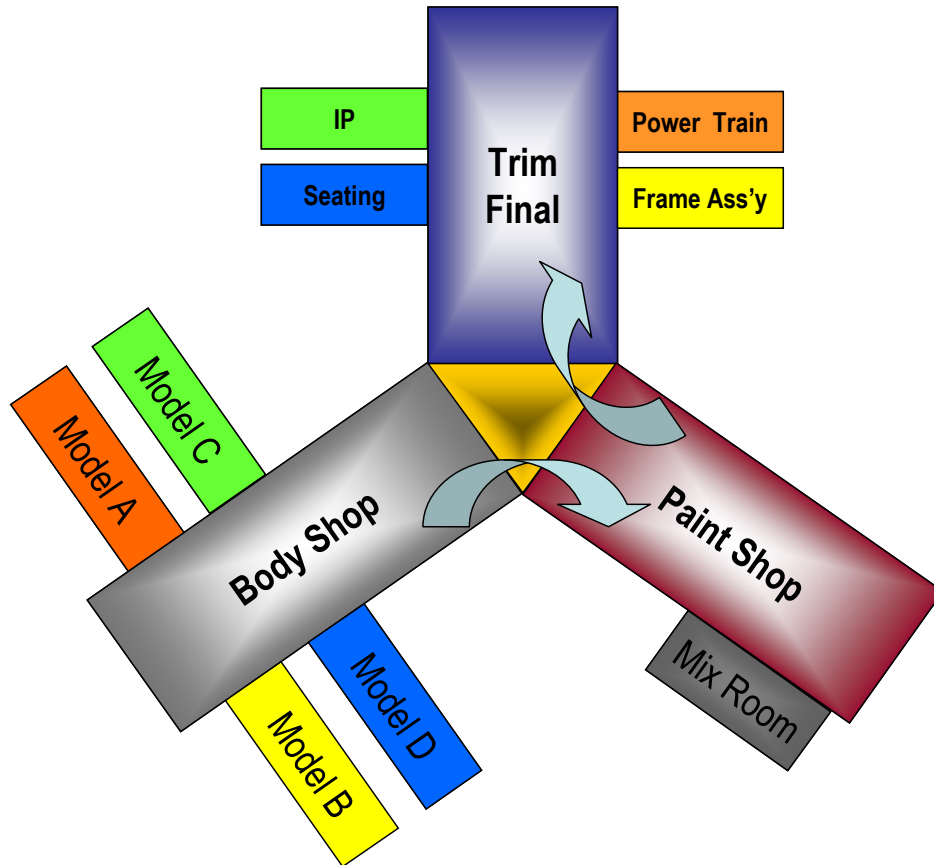
The Framing System is also a skid on a roller conveyor system that will utilize generic skids for current and future models to transfer the vehicle from station to station. Underbody fixturing for the current model is by static fixturing, while the

future gaging will occur with dump-in locators. All upper body fixturing is done by geometry docking end effectors to provide flexibility for the future models.

All closure panel assembly systems are robotic transfer systems that utilize separate static geometry fixtures—one for the current product, the other as protected space for the future model that is in reach of existing robots. Also, robotic roller hemming is used for all hemmed panels.

A potential next step for the North American integrator-operated body shop would be to incorporate the paint and final assembly into a full vehicle assembly facility. Figure 14 was presented by Kuka at the 2005 CAR Management Briefing Seminars as a possible next generation plant. The model as presented is applicable for either an OEM run facility with supplier partnerships, or conversely, an integrator could manage the entire facility. Importantly, this model has similarities to a couple of highly integrated facilities in Europe.

Figure 14 – Next Generation Assembly

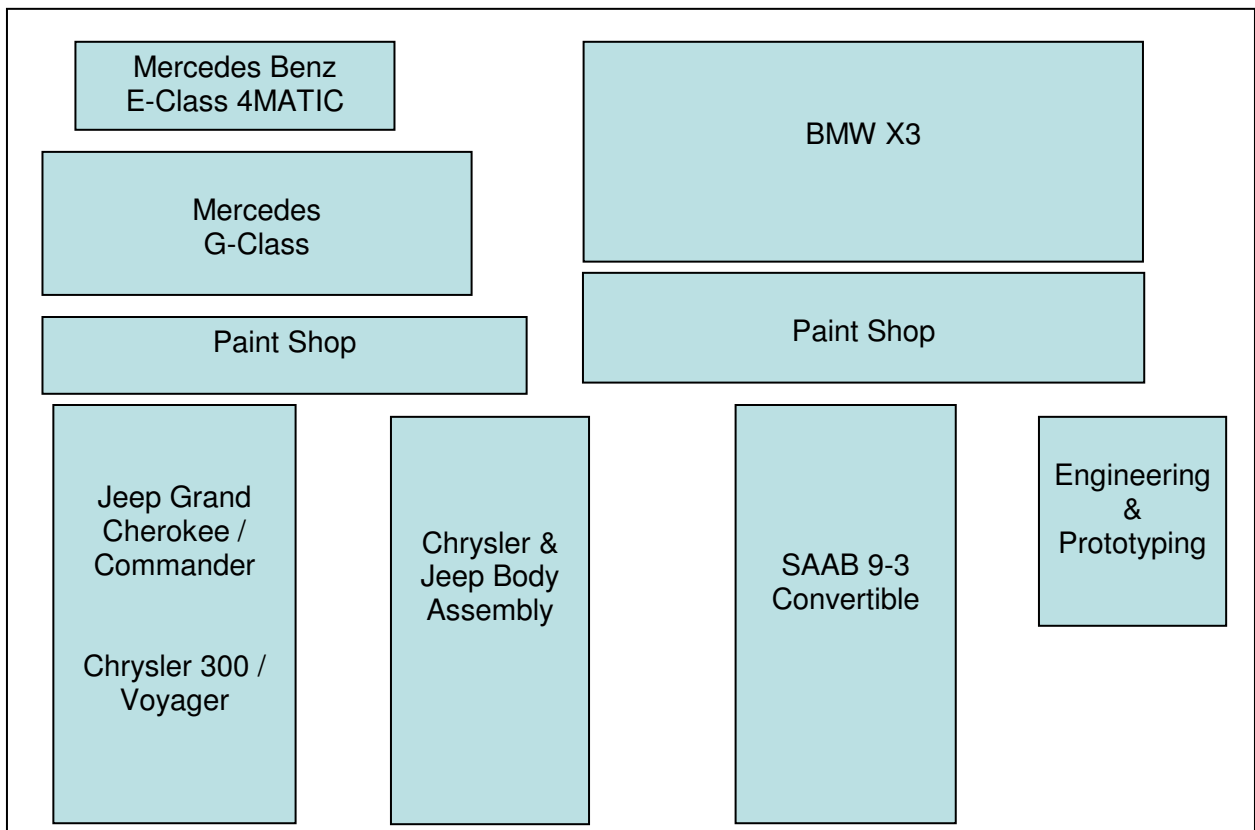


While the Kuka body shop at Toledo Jeep stands as the best example of integrator-operated body assembly in North America, the Magna-Steyr facility in Graz, Austria is an example of flexible body assembly, with the added value of complete vehicle manufacture and assembly.

Magna Steyr is a subsidiary of Magna International and has complete product and process engineering capability, as well as tooling and vehicle manufacturing resources. The company builds approximately 250,000 vehicles per year at its facility in Graz Austria, and also provides a strong logistics capability; they manage more than 2,050 suppliers, and 1,300 trucks per day at their facility.

The Magna-Steyr facility builds vehicles for four different manufacturers, using five different final assembly buildings, two paint shops and takt times ranging from 2 to 24 minutes. The Graz facility produces seven DaimlerChrysler vehicles (five Chrysler group vehicles, and two Mercedes-Benz vehicles), one GM vehicle (the SAAB 9-3 convertible), and one BMW model (X3) (Figure 15). In addition to the large number of products produced, it is also important to note the wide variety of manufacturing pathways employed. The BMW product is considered high volume (over 150,000 per year) with a dedicated paint shop, while the Mercedes G-Class and Mercedes Benz E-Class 4matic and the SAAB 9-3 convertible are built using the coachbuilder model. Of particular interest for this report, Magna-Steyr uses a highly flexible body (and assembly) process for the five Chrysler Group products.

Figure 15 – Magna Steyr Graz Austria Assembly Facility

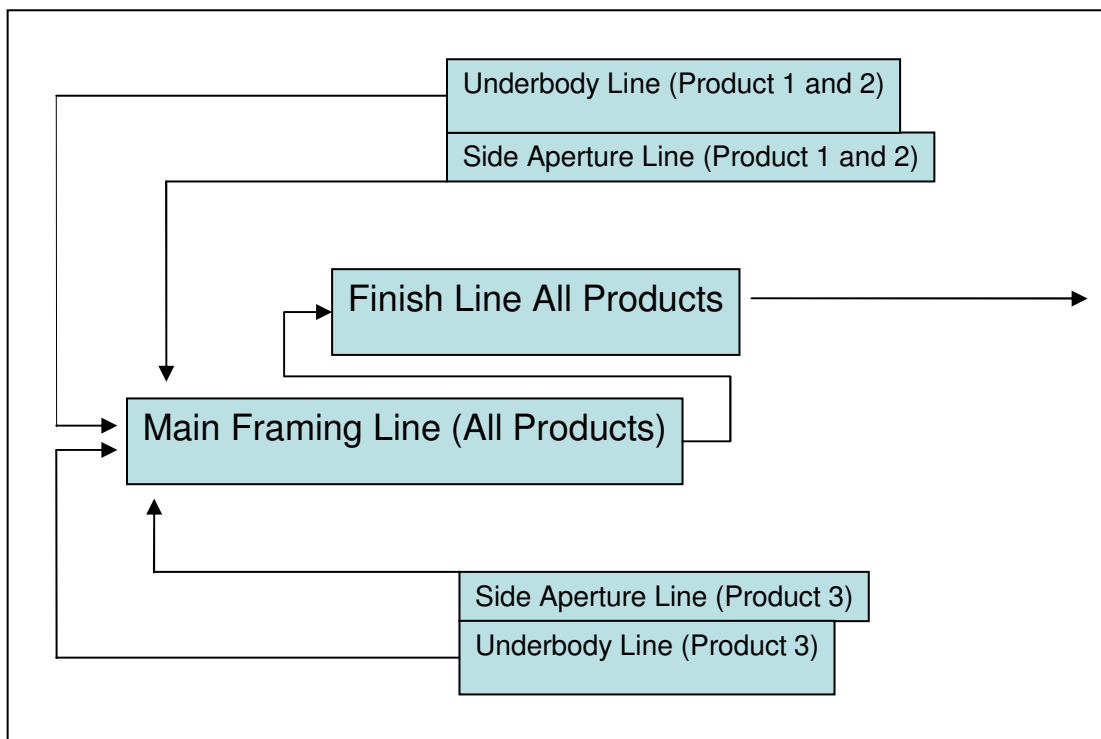


A majority of the components used for the Chrysler products are shipped from the same suppliers that manufacture the components for North America. However, some components are sourced from single-source European suppliers. Magna-Steyr stamps some sheet metal parts in Austria using duplicate dies that

they engineered. The company also engineered and manufactured much of the assembly equipment used in their body and final assembly operations.

The Magna-Steyr Chrysler Group body assembly facility uses traditional manufacturing processes, with some alteration for flexibility (Figure 16). As with many traditional body shop layouts, the underbody, framing, and side aperture lines are unique for differentiated vehicles. However the finish and main framing lines are able to assemble several vehicles. Magna-Steyr increases the flexibility of the dedicated lines by relying on modular welding stations. The following diagram shows a stylized representation of such a line. The implementation of more flexible underbody and framing lines would present an important next step in such a model.

Figure 16 – Stylized Multi-Vehicle Body Assembly Line



Final assembly for the Chrysler Group vehicles manufactured at the Magna Steyr Graz facility presents a “we can assemble anything in-line” approach. The system uses an adjustable, highly flexible, four-arm hanger system. The hanger system is the critical element in achieving a varied model mix. It is flexible enough to assemble a sport utility vehicle, a minivan, a sedan and a station wagon, with little restriction in model mix. Further illustration of the overall flexibility of the assembly process is the engine marriage system. Magna-Steyr can install transverse, longitudinal, or four-wheel drivetrains in-line, as needed. The flexibility of the paint shop also is worth noting. The paint shop used for the Chrysler group products also serves the E-Class, G Class, and SAAB 9-3 convertible built at the Graz complex.

Currently, Magna is performing “peak-shaving” for the Chrysler vehicle—adding capacity outside of the manufacturers’ assembly system to meet peak demand. In this case, it can more accurately be described as producing a low-volume of vehicles for a new market. On first examination, the plant may be viewed as similar to a complete knock-down assembly (CKD) operation. However, a more thorough investigation of the facility suggests the manufacturing processes used at the Graz facility are more advanced than traditional CKD facilities. It is also quite clear that this system is easily transferable to manufacture uniquely developed low-volume vehicles.

C. Coachbuilder Model

The second of the integrator models presented is the coachbuilder. The coachbuilder model is a dedicated product manufacturing system. Each vehicle is manufactured using dedicated equipment (body and/or final assembly), usually with slower cycle times and lower-cost tools. Commonly, the coachbuilder is also responsible for vehicle engineering and integration, program management and manufacturing engineering. The coachbuilder model relies on the overall strength of the integrator to perform, in essence, as a small-scale car company. The ability of such a model is quick response, with few limitations placed on product design. The coachbuilder must offer the ability to engineer and manufacture vehicles that do not ‘fit’ into the manufacturer’s system, at a speed and cost the manufacturers can not match.

The Chrysler Crossfire is an example of a coachbuilder developed and manufactured vehicle. Karmann, which produces the vehicle at their Osnabuck, Germany facility, built 19,426 Crossfire coupes and 16,250 convertibles in 2004. The company shared responsibility for product engineering, program management, die development, and manufacturing process engineering for the Crossfire with a small team from DaimlerChrysler. The team used the OEM’s development system when possible for the program, with Karmann and Chrysler management involved in milestone approval. Karmann’s choice to re-use the body structure from the Mercedes-Benz SLK roadster was an important cost and time savings element of the Crossfire. By using many of the validation tests from the SLK as a proxy for the Crossfire, Karmann was able to develop the coupe without any prototypes (the Roadster convertible did require 11 prototypes).

Karmann was responsible for complete die development. The program uses Karmann’s die manufacturing standards, and the dies were manufactured at their die shop. The dies for most major parts were completed in approximately 10 months. Approximately 60 percent of the stampings are done at Karmann’s on-site stamping facility.

The body shop consists of mostly dedicated sub-assembly and underbody lines using standardized reprogrammable flexible robots. Many of these robots were reused from previous programs. However, the manufacturing process—the layout of the facility—was new for the Crossfire. The cells were shared with other programs during start-up, but are for the most part dedicated to Crossfire production. Karmann assembles the vehicle on a stand-alone line, but employs a shared paint shop using batch production.

D. Integrator-Operated Low-Cost Tooling (and Assembly) Model

Each pathway places an emphasis on lower tooling investment, while accepting a potential piece cost penalty. However, the low-cost tooling and assembly model relies on technologies and processes that greatly reduce the capital investment. The model is built on the premise that there are tooling alternatives that, while unacceptable for high-volume applications, may offer great opportunity for low-volume programs. Importantly, while the standards for low-volume dies may be different from high-volume, there can be no difference in the final part quality.

Several vehicle manufacturers have developed tool and die standards based on historical runs of 250,000 per year or more, with an expected life of five to seven years. Arguably, these standards lead to over-engineering for a die that produces 35,000 or fewer parts per year. CAR considers the concept of lean dies (as described in Appendix 1, Section H) essential to the successful execution of a low-volume vehicle program. However, the low-cost tooling pathway further lowers die cost via the use of alternative materials.

There are several die materials that are capable of producing high-quality, low-volume parts. However, because these materials are not capable of meeting the durability standards for a high-volume program, they are not considered for production by many manufacturers. These materials are:

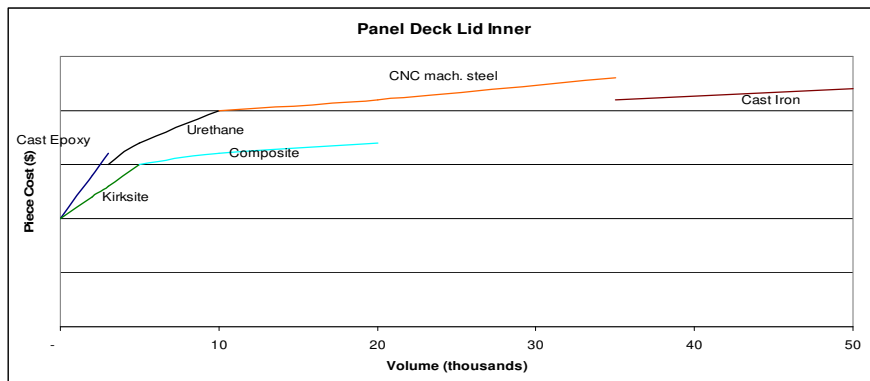
1. Mass cast epoxy dies: these dies utilize a poured epoxy solid mass with a urethane face coat. Production wear plates are used for vertical guidance between all moving parts. Mass epoxy dies can be utilized for class II components with a volume of less than 3,000 parts.
2. Kirksite dies: these are traditionally used for automotive prototype dies. The Kirksite die process is based on CNC-machined surfaces cut to math data, and can be used for class I and II surfaces with volumes less than 2,000. The tooling process requires eight weeks.
3. Red urethane plank dies: these dies are CNC-machined from math data and can produce a very detailed surface. The construction procedure pours a mass cast epoxy die below a two inch red urethane plank. The material is very durable in compression but has limitations in tension. The red plank dies can be utilized for Class I and Class II and have been used for production levels of 10,000 panels. The tooling process requires eight weeks for prototype dies.
4. CNC-machined simple dies: CNC-milled steel components, which are positioned on generic die sets. This cost-effective method of CNC-machining steel dies will produce Class I and Class II with a very durable surface. The generic die sets are reusable but not the steel die material. These dies require a sixteen-week time frame.

5. Steel dies with designed standard die sets: although these do not adhere to typical production die design standards, they are used by major stamping facilities in North America. This die type has very good results for small and medium parts. Due to the CNC milling of steel surfaces, this process is stable for Class I and Class II parts with high production levels of sheet metal stampings. The tool process saves cost and timing when compared to cast iron production dies for the following reasons: 1) the elimination of cost and timing of Styrofoam patterns, 2) the elimination of cost and timing of programming and machining of all linear surfaces, 3) the partial savings of the construction of heels, pins, bushings, production wear plates and the fittings of the upper and lower die, and. 4) the purchasing of the designed die set must be added. In comparison to a traditional production die, the time savings is approximately six weeks and the cost is reduced by 10 to 20 percent.

6. Low-volume cast iron production dies: cast dies can be CNC-machined to ensure Class I quality. Costs are reduced by designing reusable generic components and sizing the die to the part and not to the press. Additionally, castings were reduced in weight with thin wall concepts, vertical guidance was achieved with simple heeling and pin and bushings, trim edges were welded and then CNC-milled, etc. These types of cast iron dies can supply typical high-production volumes of sheet metal stampings. The reduction in tool time would be approximately eight weeks with a savings of 10 to 15 percent of traditional production dies.

The die industry has experience with each of these die materials and understands the capabilities and limitations of each. This model leverages the working knowledge, and the creativity of die makers to greatly lower the fixed investment for a low-volume program. Figure 17 presents a stylized cost curve for a deck lid. The figure shows that each of the die materials is cost-effective for a narrow volume range. The low-cost tooling pathway relies on identifying the best die material for the part and volume to create stamped parts that meet the quality requirements, with the lowest capital investment. Importantly, because of part geometry and other influences, different parts may require different die materials for similar volumes. Thus each part for a vehicle would require a cost curve similar to the one shown below.

Figure 17 – Stylized Cost Curves – Selected Die Materials



The fragility of the dies would likely require that the parts be produced outside of the traditional stamping facilities. The creation of low-volume stamping practices would greatly increase the effectiveness of this model. It is apparent that the low-cost tooling model would be a significant change in practice for manufacturers. However, it is possible that, given cost pressures, it may present a viable way to cost-effectively deliver stampings for a low-volume vehicle.

Another element in the low-cost tooling concept is the use of laser trimming. Trim dies, by their nature, are expensive to construct. It is difficult to eliminate cost in a trimming operation due to the accuracy required. Five-axis laser trimming can be effective on small and medium size parts with intricate trimming conditions. Again, a study must be done to each part to analyze the cost and time of laser trimming in comparison to trim dies.

While it is logical to assume that the stampings produced in this model may be sourced directly to a vehicle manufacturer or integrators body assembly facility, this pathway can be carried further to include a low-volume body assembly as part of the model. The use of low-volume robotic welding cells and roller hemming could allow for the assembly of stampings into sub-systems, or even more complete body assemblies.

E. Post Production Vehicle Alteration Model

The final pathway re-examines all that is assumed about low-volume vehicles. This model suggests that, rather than spending resources on developing a unique vehicle, it may be more effective (i.e., give a higher rate of return) to invest in differentiating a current vehicle through accessories. While we described this investment as the post-production vehicle alteration model, it may be more descriptively coined the 'SEMA' model.

The Specialty Equipment Suppliers Manufacturers Association (SEMA)—those companies that supply the aftermarket—have found that many United States. Car buyers are strongly interested in customizing their vehicles. According to SEMA, approximately \$31 billion dollars were spent on customization in 2004. The SEMA model suggests that manufacturers should work with aftermarket suppliers to leverage their aftermarket cachet while giving customers an opportunity to easily customize their vehicles. Currently, Toyota's Scion division is the most effective example of such a strategy. (Scion is investigated more closely in the Case Studies section of this report). Increasingly, manufacturers are affording key aftermarket suppliers the opportunity to work with early production vehicles to assure that aftermarket product offerings are better-integrated, and market-ready at vehicle launch. Some manufacturers are leveraging the creativity of these suppliers by displaying their interpretations at automotive shows and other events.

Several other manufacturers have created strategies that address the aftermarket, yet there are questions as to whether these organizations have positioned themselves to take advantage of the speed and creativity within the SEMA community. The ability for a company to leverage a virtual supply base of

'cool' aftermarket suppliers is essential to this model. Thus, the SEMA model relies on quick, low-cost responses to the market. All too often, the structure and accompanying slowness of some vehicle manufacturers limits effectiveness in such an environment. This model may be more effectively run by integrators (i.e., vehicle integrators, mega-dealers or some other such outside party). The model also may offer the opportunity to co-brand vehicles with other consumer brands

As part of this project, and with the support of SEMA, CAR interviewed several SEMA member companies. The group included, among others, two aerodynamics package producers, a suspension specialist, and a seat cover maker. The companies each presented successful business strategies to fill the needs of vehicle customization. Yet it was apparent that some SEMA suppliers were not capable (or did not want) to participate in a more structured OEM model. Conversely, there are many aftermarket suppliers that offer strongly branded products, with great opportunity to assist in vehicle differentiation. Many of these companies lack the resources to breach the manufacturers' walls of bureaucracy. SEMA has done an excellent job of offering guidance to such companies. However, there remains much opportunity for suppliers, manufacturers and SEMA. CAR expects to continue to work with SEMA and its members to continue to explore this model.

While each of these companies interviewed represented creativity and cachet, one company stood out as an example of how the SEMA members can bring innovation and differentiation to low-volume vehicle manufacturing. Katzkin Leather Interiors, Inc. in Montebello, California manufactures aftermarket leather seat covers. Their seat covers are sold through dealerships and installed by restylers. Consumers can use a dealer-located design kiosk to choose from over eighty colors and textures, and add embroidery and piping to create a unique seat. The order is then filled within 48 hours, and shipped to the restyler for installation. The company is the sole source for aftermarket leather for Mopar, and has been licensed by GM to reproduce the GM trademark on their products. The Katzkin model presents an interesting seating option for any low-volume vehicle program.

One final caveat regarding the post-production model—and its application back to the more traditional concept of low-volume vehicle production: it is often difficult for suppliers to convince manufacturers to accept new manufacturing technologies—especially those that do not necessarily meet high-volume tooling requirements. The manufacturer often is more willing to accept something that has a proven track record. The post-production alteration model may serve as a proving ground for new technologies. There are numerous aftermarket aerodynamics packages offered. In order to differentiate their package, a SEMA supplier might partner with a die maker to offer a hood with a scoop as part of the package. This hood could be created inexpensively on a low-cost die (using materials highlighted in the low-cost pathway), and use manufacturer engineering data and approved steel. The part would then be assembled using a flexible roller hemmer. The SEMA supplier would have an original equipment quality hood to include with the plastic aerodynamics package, and the company that produced the hood would have evidence of a successful technology application.

IV. Case Studies

A. Introduction

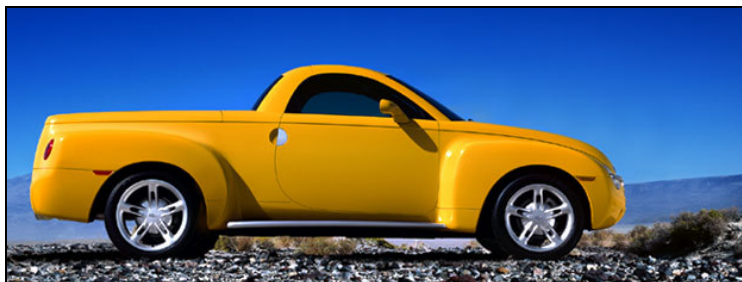
The Center for Automotive Research selected four low-volume vehicle programs to study. These case studies present opportunities to investigate current strategy and illustrate techniques that may or may not be effective for low-volume manufacturing. Importantly, it is not our intent to identify successful—or unsuccessful—projects. Instead, the emphasis will be on highlighting elements that we believe provide further insight into the challenges and opportunities of low-volume vehicle manufacturing. Additionally, these case studies are useful presentations of the pathways presented earlier in the report.

B. GM SSR

General Motors contracted with ASC to develop a facility in Lansing, Michigan to co-produce the Chevrolet SSR roadster/pickup (Figure 18). The SSR had a 24-month development program and was launched in the summer of 2003 with a projected volume of 10,000 units per year. The body-on-frame design uses a carryover truck frame from GM's GMT360 (Chevrolet Trailblazer, GMC Envoy) platform. The program will be discontinued in 2006.

The ASC Lansing plant is a complete module facility servicing the General Motors Lansing Craft Centre (LCC). ASC is responsible for producing all 42 major subassemblies in their plant and supplying those assemblies to LCC approximately five miles away. The subassemblies include: body structure assemblies (motor compartment, front floor, rear floor, body-side inner and outer, fenders, doors, closure panels, etc.), modification of frame, engine and transmission dressing, wheel and tire assembly, fascia assembly, instrument panel assembly, door trim, and console assembly, among others (Figure 19).

Figure 18 – Joint ASC/GM Produced SSR



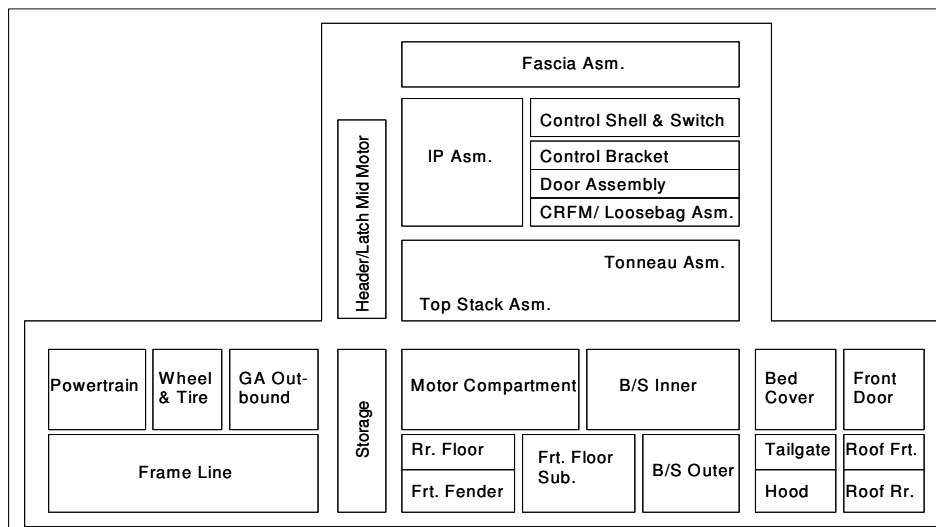
While the SSR represents somewhat of a mixed bag in terms of marketing, the ASC facility offers some excellent illustrations of a low-cost tooling pathway, and how modularity can play a role in supporting low-volume manufacturing. CAR believes this facility offers a valuable case study in low-volume modular assembly for the North American market.

It is important to note that the dies for the program were manufactured to meet the traditional General Motors standards. Consequently, it was likely difficult for GM to create a profitable low-volume vehicle program. Unlike the GM dies, the ASC facility does not represent a high-volume, fixed-technology approach. The most automated aspect of the plant is the frame-length reduction (about 6 inches) on the GMT-360 frame which arrives pre-assembled. The automatic process, over several stations, uses a laser to remove a middle piece of the frame and then reconnects it. Additional reinforcements and brackets are also added in this process. From that point forward, there is only one station with any additional robotic welding (fender sub-assembly). Several cells (powertrain, instrument assembly and convertible roof) have low-cost automated guided vehicles (AGVs). The guide wire for the AGVs is taped to the ground to allow for layout modifications and flexibility.

The body shop welds sheet metal body parts into subassemblies using only resistance spot welding. These are then shipped to LCC where they were assembled into a complete body-in-white. The tooling at ASC is dedicated, but simple. Theoretically, capacity could be quickly added simply by changing the layout and by adding tools to the body shop. ASC took great pride in the fact that much of the tooling was recycled from closed GM facilities—and thus was extremely inexpensive. Important stations in the body shop had welding counters attached to welders as an error-proofing device—an operator is not able to unclamp a part if any welds are missing. All hems are performed by a simple Fuji table top hemmer.

A final comment on this program is somewhat of a moot point given the termination of the SSR program; however, the program does add some insight into a potential business model. ASC's Lansing plant operated on one shift. Most of the ASC facility was flexible enough to be moved at the end of a shift (most fixtures were either on wheels or not bolted to the ground). Potentially this plant could have built the complete modules for three vehicles—one on each shift.

Figure 19 – ASC's Shop Layout



C. Corvette Z06

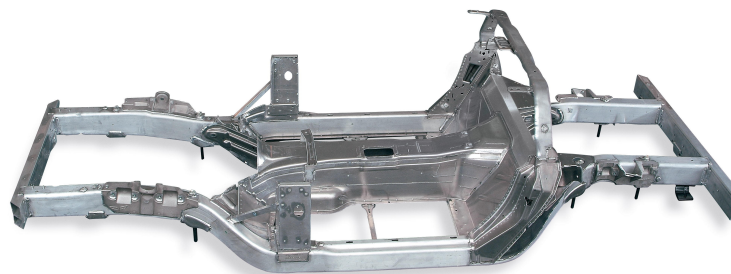
The Corvette Z06, while externally not highly differentiated from the base model, replaces the steel spaceframe found on the standard C6 Corvette with an aluminum frame (Figure 20). Thus it presents a major change in a product—albeit not necessarily a visually noticeable one. The Z06 shares an assembly line and underbody with the baseline C6 Corvette at GM's Bowling Green Assembly Plant (BGAP) in Bowling Green, Kentucky. At a production volume of 7,000 units per year, the Z06 represents the most sophisticated low-volume vehicle in production at GM.

Figure 20 – Chevrolet Corvette Z06



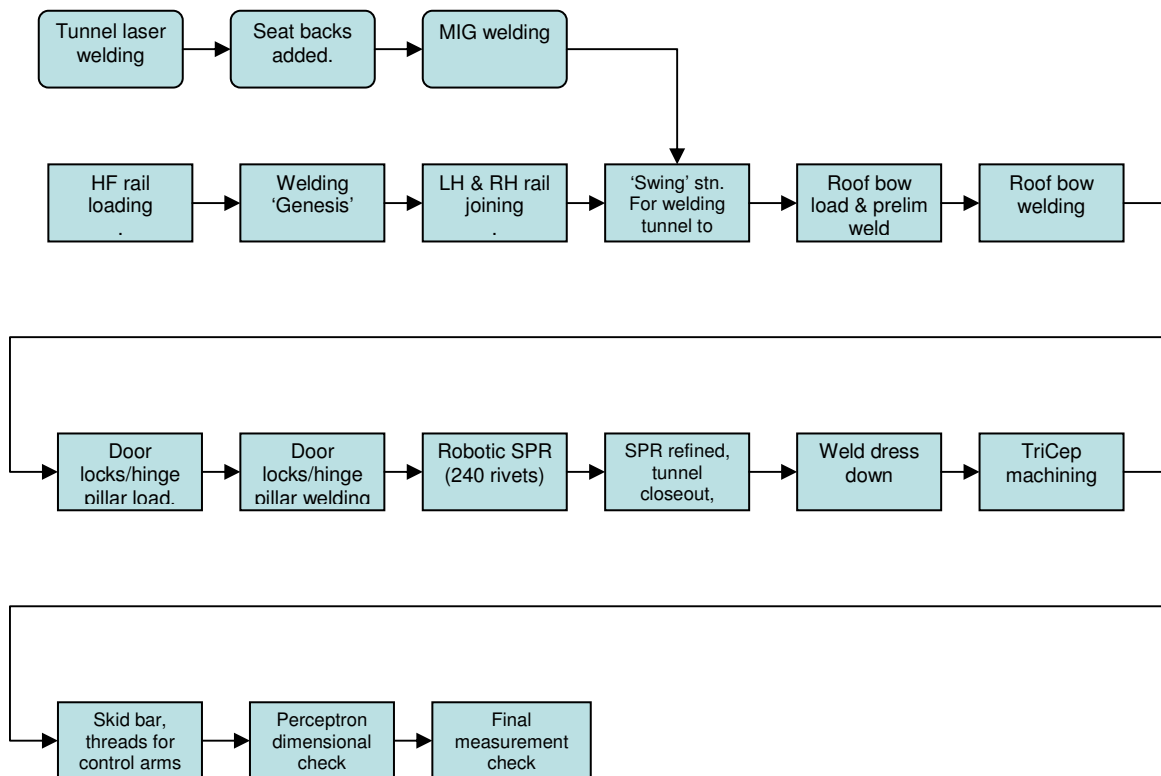
In order for the Z06 to compete in a market which includes some of the fastest vehicles in production, GM vehicle engineers set performance targets significantly higher than the baseline C6: including mass reduction, improved handling, decreased noise and vibration, and increased horsepower. However, to maintain the Z06's affordable price relative to its competition, GM required a Z06 assembly that would mirror the steel baseline C6 final assembly so the two vehicles could share the same assembly line with little process variation. In an effort to significantly reduce vehicle mass, Dana Corporation's Structural Solutions Group was contracted to develop an aluminum spaceframe (Figure 21). The spaceframe is manufactured at Dana's Hopkinsville, Kentucky plant, sixty-five miles from Corvette's final assembly plant

Figure 21 – Z06 Spaceframe – Manufactured by Dana



The frame represents several firsts for Dana. It was the first time they had primary design responsibility for a frame. It was also Dana's first frame made entirely of aluminum. The frame is built on a stand-alone line at the Hopkinsville facility (Figure 22), with 17 employees per shift, running two shifts. The line has a cycle time of approximately 20 minutes. Dana engineered the dies for the frame using their lean die standards, and worked with a supplier to build the dies. Although the program is intended to serve as an opportunity to highlight engineering and manufacturing capability, Dana expects the return on investment to equal or better the industry average.

Figure 22 – Z06 Production Line



The spaceframe includes 8 castings, 21 extrusions, and 63 stampings. Dana uses MIG welding, laser welding, and self piercing rivets for assembly. The use of aluminum castings allowed for part integration not employed on the baseline C6. A hydroform die is used to construct the longitudinal aluminum rails. This is a carryover die that stamped the steel rails for the baseline C6, resulting in dimensionally similar aluminum and steel rails. Laser welding—a total of 14 meters—is used for several joining locations. For example, the joining of the tunnel requires ten meters of laser welding done off-line using 4 fixtures in one cell. The frame also has 236 robotically applied self-piercing rivets. The completed frames are shipped to the Bowling Green Assembly Plant.

The Corvette Z06 aluminum spaceframe suggests important lessons from several standpoints. Although the manufacturing processes used at the Dana Hopkinsville, Kentucky facility are fairly standard, the program incorporates

efficient die design—including tool re-use, and limited vehicle assembly line changes—to reduce program costs. It also represents one of only two spaceframe programs currently built in North America. Since the spaceframe has seen an increased interest—specifically from European manufacturers—it is valuable to explore this frame strategy. CAR will further investigate two spaceframe concepts—the General Motors Kappa platform, and the use of roll forming—later in this report.

D. Scion

Scion is the embodiment of the post-production vehicle alteration approach to low-volume production: build a ‘monospec’ car at the factory to keep costs low despite low-volumes, and do any necessary customization downstream—either at portside or at the dealer. CAR can not estimate how successful this approach has been from a cost point of view, but from a revenue perspective (price maintenance, volume growth, conquest rates) Scion appears to have been very successful.

Toyota’s initial attempt to access the North American youth market was the Genesis Project. The first such production was executed wholly within the Toyota brand, leveraging existing vehicles (e.g., Celica and MR2) and developing new ones with a more youthful focus (e.g. Matrix and Echo). This approach was not effective in creating positive brand awareness among younger buyers. Toyota then decided to establish a new brand, standing apart from Toyota and focused more explicitly on youthful buyers.

Recognizing that younger buyers had expressed an interest in “not driving what everyone else has,” Toyota realized Scion models would have to be profitable at relatively low-volumes. Additionally, market research indicated that younger buyers were very eager for individually customized or personalized vehicles. Toyota was deemed “not very customer friendly” in this regard, as the company had long gone to market with a trim-level approach—grouping options into low, medium, and high packages rather than allowing for a great deal of car-by-car variation. However, the factory in Japan could not handle the variety required, as:

- a) this would drive costs up and
- b) the 30-day lead-time required for production and ocean crossing would be rejected by impatient youthful buyers.

The resolution for these issues was to greatly reduce the production options in Japan, so the factory would not be burdened by high levels of variation. Scions from the factory vary only by automatic versus manual transmission and external paint color (all interiors are black.) To avoid long lead-times, final customization would be done in the United States., either at the port of entry or at the dealer.

There was another reason for offering high levels of local personalization, beyond customer demand for it and impatience with waiting for it: it was very important that dealers hold very little Scion inventory. Market research had shown that Scion buyers were distrustful of the price haggling process, Toyota

needed to fix prices. Although dealers set the transaction price, the limited availability creates price pressure. Any dealer with a 60-day supply of cars would find the pressure too great and likely start cutting prices to increase sales. To remove that temptation, Scion had to ensure that dealers had only enough vehicles in inventory to meet customer demand, while leaving little excess to create downward cost pressures. This requirement would be met by having dealers order up mildly-customized cars from Toyota only as customer orders were placed, holding the vehicles just long enough to do final customization. The accessories would be added at the port of entry or at the dealership. The other benefit of minimal inventory and thus minimal price cutting was better dealer margin maintenance. This was critical to the Scion business model: to address low-budget youthful buyers' needs, dealers could not make the same high margin on a Scion as on a Toyota. Obviously, this model relies on providing a desirable product at a market competitive price point—something that the Scion brand appears to have done well.

One helpful feature of the Scion accessory program (from the dealer's perspective, at least) is that, as factory-approved modifications, these can all be rolled into the financing package—reducing the “hit” the customer takes. Importantly, it was reported that the accessories, and the dealer installation of these accessories, have not generated any noticeable warranty cost increments.

The Scion project appears to be a great success for Toyota: all sales targets are being hit or exceeded (currently 150,000 units annually, divided among three models), without the use of incentives. Additionally, the average age of Scion buyers is dramatically lower than for Toyota as a whole; the conquest from non-Toyota owners is approximately 80 percent. Toyota has effectively used limited funds for advertising, and the dealers appear to be very pleased with the brand.

It is interesting to note that Toyota appears to have applied some lessons learned from Scion on their new FJ utility vehicle. Dealer-installed accessories are expected to be an important part of the FJ marketing strategy. Finally, it is worth noting that the Scion team in Torrance has effectively leveraged the resources of The Toyota Motor Company—there are less than twenty people on the Scion payroll.

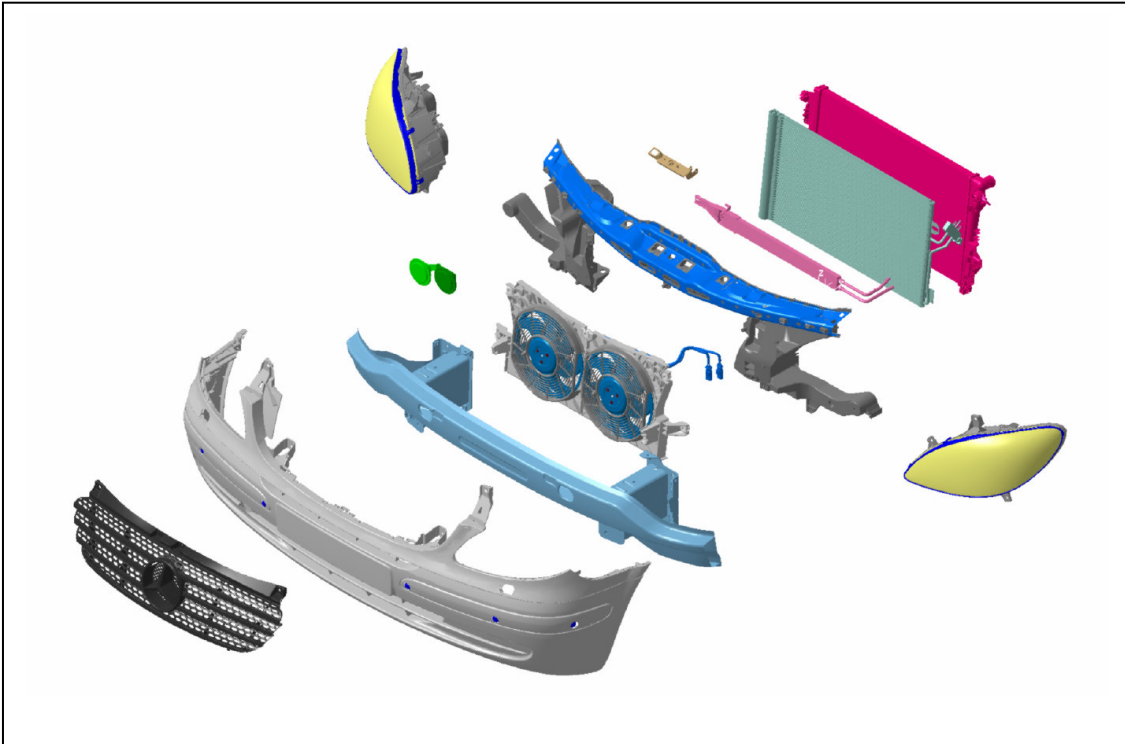
E. Materials as an Enabler for Low-Volume

The selection of materials can greatly enable the cost effectiveness of a low-volume vehicle program. There are numerous material choices that offer such opportunity. The Z06 case study illustrates the implementation of aluminum as a material that offers lighter weight for improved performance. CAR also investigated several applications of plastics for implementation into low-volume vehicles. Three of those that CAR believes offer opportunity include: 1) hybrid (material) front-end systems, 2) integrated roof modules, and 3) blow-molded seatbacks.

The hybrid (material) front-end carrier module (Figure 23) can include the cooling system, head lamps, bumper system, hood latch mechanism, lighting system, and air intake ducting. Such a strategy requires the use of an open body-in-white

front-end strategy. While European manufacturers have incorporated the open ended design strategy more rapidly, North American vehicle manufacturers have commonly used a closed front-end design. Because of the open-end design, the front-end module must contribute to overall stiffness, and it is essential that the manufacturer work closely with the module supplier. Increasingly, North American manufacturers appear to be adopting the open ended architecture, and embracing front-end modules.

Figure 23 – Front-End Module Components



First use of plastic/metal hybrids involved over-molding via injection molding. The creation of a composite piece made of plastic and metal parts with mechanical locking between the two components (produced through injection molding or extrusion) enables production of highly load-resistant and low-cost parts. With the help of injection molding technology, plastic ribbing and bracing are molded onto the metal parts or metal profiles. These plastic structures enhance the capacity of the metal construction through optimal transmission and distribution of the forces in the component.

In comparison to conventional injection molding, complex structures and performance (that plastic alone has been incapable of producing) can be created with plastic/metal hybrid technology. Composite plastic/metal designs can have a higher load capacity than open or even closed metal sections. With optimized ribbing the hybrid solution is similar to a closed metal solution, even under torsional load.

The technology is applied in practice in the Audi A6 AVANT and in the Ford FOCUS front-end modules. Reportedly, use of the technology in Audi vehicles led to a 10% reduction in production costs and a 15% reduction in weight. After initial experience with hybrid technology Audi is implementing this technology successively in other models.

In the case of the Ford Focus, a new step has been taken towards implementation of hybrid technology through consistent integration of functions into the component. In addition to narrow tolerances, the new insurance requirements were able to be met for this component through integration of the hood lock into the front-end. Reportedly the program resulted in a 20% reduction in part cost, a 50% reduction in investment cost and a 40% reduction in weight.

To achieve the needed balance of weight reduction and stiffness, front-end modules use a combination of steel and plastic structural parts. The ability to create adhesives that deliver required bonding characteristics has been a key enabler for these modules. By bonding a continuous joint and forming a closed section in plastic-to-steel components, the bond creates a stiffer component than previous bonding methods. Such strategy offers further weight reduction, and increased structural stiffness.

Another modular concept enabled by material selection is the plastic hybrid roof module. Bayer Material Science LLC has developed an integrated roof module concept that directly enables low-volume production opportunities. It enables a flexible assembly strategy, decreases capital investment, and reduces labor content at the assembly facility. The concept relies upon plastic metal hybrid technology for structural components (e.g., roof bows). The metal profile is placed in an injection mold, and plastic is injected around the profile. A polyurethane headliner and foam, PUR carrier and a paint film are used to create the roof panel then are combined with the plastic-metal hybrid structures. Such a strategy would allow a vehicle manufacturer to offer several variations of a roof (e.g., a base roof, a sunroof and a panoramic roof with assembly plant investment).

A final material substitution offered for example is the use of blow-molded seat backs designed by Dow Automotive. The flexibility of the blow-molding process allows the integration of geometric features such as grips, molded channels for head rest guides, support bars, and anatomically designed shells for improved seat comfort. Short rise stamped steel brackets are bolted to the lower right and left corners of the blow-molded plastic shell to connect the seatback to the vehicle floor pan and allow the seatback to pivot and fold. Conventional seatback designs utilize either a stamped steel shell welded to a steel tubular structure along the shell periphery or a primary stamped steel shell with multiple stamped steel shell reinforcements welded together. These designs are optimized to provide structural stiffness by careful design of the tubular members or metal cavities defined by the stamped shells, and to use the plastics to manage deformation of the sheet metal. The blow-molded seatbacks present opportunity for low-volume and allow for a greater number of seat options at lower costs—in part because of the flexible manufacturing processes and lower cost tooling.

Daimler-Benz introduced the world's first volume-produced car seat containing a load-bearing plastic/metal composite part on the 1997 Mercedes-Benz V-Class minivan. The seat back combines a metal insert and polyamide 6 resin. The resin is a 30 percent glass-fiber-reinforced, impact-modified nylon that provides high strength and toughness.

The seat back, which normally consists of 20 to 30 parts, was reduced to only one component. This plastic back with frame-stiffening ribs also offers an integrated headrest support and an integrated belt housing and mechanism. A metal frame is married to the plastic on the side where the seat belt is attached to the seat at shoulder height instead of being attached to other parts of the car/frame.

The rear seating system offers reduced cost, increased versatility, reduced weight and a significant reduction in the number of component parts when compared to a traditional seating system. The seat, which weighs 87 pounds, is 30 to 50 percent lighter than traditional automotive seats, and the cost savings can reach 10 to 20 percent—according to Daimler-Benz. The seat also features a seat pan made from ABS resin.

While these applications are viable for higher volume programs, their low cost and quick development (tooling) present even greater opportunity for highly cost-sensitive low-volume programs. Further, modularity becomes an enabler for the implementation of several low-volume material substitution applications. The addition of low-volume vehicles into a manufacturing facility can create a marked increase in inventory. The ability to incorporate pre-assembled modules into low-volume vehicles limits the number of new parts processed by a manufacturing facility, and thus creates less disturbance in that facility. The three aforementioned options, along with many others, must be considered when investigating low-volume manufacturing.

F. GM – Solstice

General Motors has begun production of a series of low-volume small two (two-seat) roadsters. The program, operating under the internal designation Kappa, is intended to produce niche vehicles in modules of roughly 20,000 units, with a price of approximately \$20,000 to \$25,000. The General Motors facility in Wilmington Delaware is currently producing two vehicles from this platform: the Pontiac Solstice, and the Saturn Sky. A third vehicle—expected to be a Saturn Sky re-badged as an Opel—may be in production within a few years.

The development of the Kappa program has been well documented over the past four years. General Motors has made it very clear that a key enabler for this program was the different approach taken in product development. In many ways, the program was effective because they were able to work outside General Motor's traditional product development process—a benefit shared by many other low-volume programs. The ability of the program to reach production without using integration vehicles was responsible for cost and time savings. The program also relied heavily on the corporate parts bin—i.e., using parts from

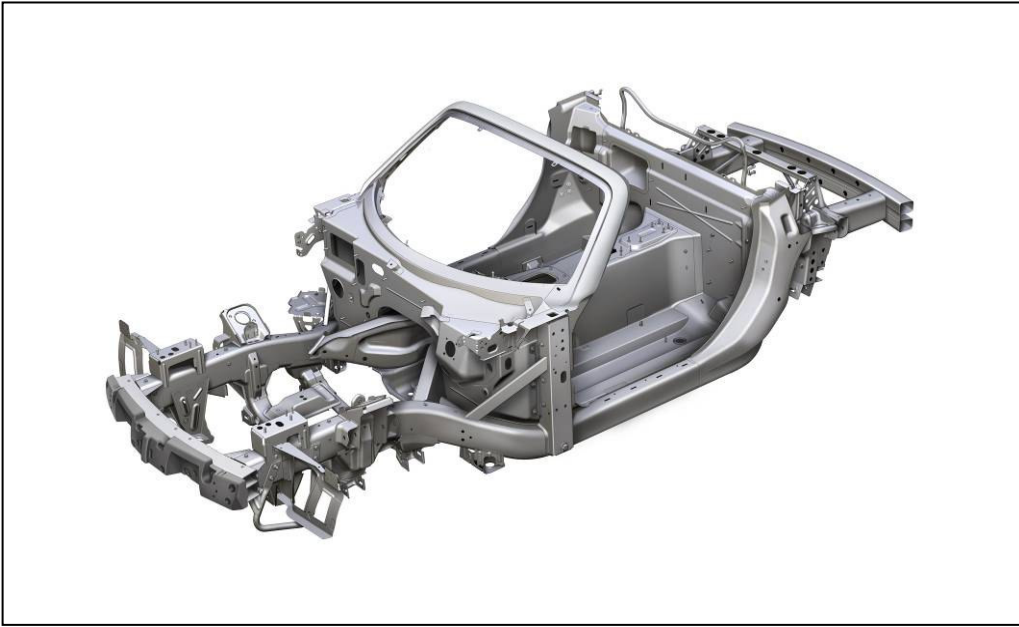
other General Motors vehicle programs—to reduce development time and tooling costs.

Although General Motors has developed a flexible body assembly strategy (C-Flex), the Wilmington plant relies on manual welding for the body-in-white. Thus, the Kappa represents an internally engineered program, built in-house on a stand-alone assembly line. As such, it is representative of the challenge faced by vehicle integrators in the North American market. While there are many reasons the Kappa program was handled internally, it seemingly would have presented an excellent opportunity for an integrator to take the lead on manufacturing (and even engineering). However, given excess capacity—an empty plant and idled workforce—General Motors had great incentive to keep production in-house.

Two other aspects of this program are worth highlighting: first, the use of a spaceframe design for the platform (Figure 24), and second, the innovative use of sheet hydroforming for many of the body panels. General Motors initially considered developing the Solstice on an existing GM platform (e.g., their Delta platform), but instead chose to develop a unique platform for the program. The company chose to develop the Kappa as a spaceframe. By not including the body panels in the structure of the vehicle, GM was able to change the appearance of the vehicle without re-engineering the entire vehicle. This design flexibility gave General Motors the ability to quickly develop differentiated derivatives for other GM brands. Many people interviewed for this project felt that the spaceframe offered interesting advantages for low-volume vehicles.

The Solstice also used sheet hydroforming technology (see technology review in section IV) to achieve deep draw forms for the outer sheet metal. Many of the design features of the Solstice would have been difficult—or even impossible—to achieve with traditional stamping technologies. The design freedom provided by sheet hydroforming combined with the flexibility of the spaceframe; make the Kappa a strongly innovative low-volume program

Figure 24 – GM Kappa Platform



V. Part Fabrication Tooling

A. Introduction

CAR investigated a number of manufacturing technologies that are supportive of low-volume production (Appendix 1 presents a more complete description and contact information for the following technologies). The list is not—nor could it be—comprehensive. Instead, it is intended to provide an overview of tooling and process developments that are aimed at reducing the high cost of tooling, when manufacturing a low-volume vehicle. It is important to add two caveats: first, it was not the purpose of this report to verify the readiness of these technologies. Instead CAR attempted to identify technologies that offer opportunity (i.e., lower tooling cost, faster development time, etc.) for a more cost effective manufacture of low-volume vehicles. CAR makes no guarantee as to the accuracy of their performance. Second, CAR made an effort to identify as many low-volume enabling technologies as possible. Although the research identified several potential technologies, it was also apparent that there were several tightly held technologies that will further reduce tooling and process costs in the future. The specifics of many of those technologies were closely guarded, and thus not readily presentable.

B. Shell Tooling

The shell tooling process CAR investigated consists of a metallic shell backfilled to create a die (Figure 26: Shell and Punch). The shell is created by applying hydrostatic pressure to a heated sheet over a castable mold. The shell production process is robust against material shrinkage because the metallic sheet is reshaped, but the molecular structure remains unchanged. After the shell is formed, and removed from the castable mold, any medium such as cast iron, aluminum, or kirksite may be used as “backfill.” The shells may be used for the drawing operation in any kind of die and features for actuators, cams, cooling lines, and brackets can be incorporated into the dies, thus eliminating the need for post-machining. The shell can also be polished to achieve class ‘A’ finishing requirements.

The performance characteristics of shell tooling are largely experimental. Shells are expected to be capable of withstanding the most demanding stamping and forming processes involved with high-volume production and have no geometric restrictions. Preliminary experiments have shown that the material used for the shell tooling is weldable and machinable; making them as maintainable as regular dies. Currently, the maximum size of a shell is limited to five feet by ten feet. This restriction is due to the available press in the shell production process. The first production application is expected to launch soon with a planned output of 5,500 parts per week.

The economic advantages of shell tooling increase with the size of the part. For larger dies, labor savings outweigh the increase in material costs resulting in savings of up to 30 percent. Lead time is also greatly reduced, as it takes

approximately four to six weeks to make a shell tool. This lead time involves a reduction of up to 45 percent when compared to traditional tools.

Spirit AeroSystems—the lead developer of this technology—created the process by combining technologies previously used in the aerospace industry. The company has partnered with two North American die shops (Richard Tool & Die and Sekely Industries) to develop and commercialize the technology.

C. Liquid Impact Forming

Liquid Impact Forming (LIF) combines aspects of traditional hydroforming and tube, pipe and stretch bending. The process is relatively straightforward: a pre-bent metal tube is submerged into a lubricating compound, sealed with end caps to preserve atmospheric pressure, and then stamped with 5,000 to 30,000 psi. During stamping, the fluid inside the pipe is used to build counter pressure which is subsequently released during the stamping process.

This technology appears to be best suited for creating roof supports, A-pillars, and other structural frame components. A variety of metals can be formed through LIF with tolerances of $\pm .25$ mm. The process allows for severe section changes, embossing, and sharp radii—bend to 150°. Production rates span from 450 – 500 parts per hour, approximately 2.5 times more than traditional hydroforming.

Cost savings stem from the increased production rates, reduced welding requirements, and the ability to flange in press. Production in stamping press may reduce costs by up to 200 percent when parts are eliminated. The process is currently under development, and not considered ready for production application. Successful tests have been completed for a variety of metals and the next step involves testing dies in the production environment. LIF reportedly can be performed in existing stamping presses.

D. Hydroforming (Sheet)

Sheet hydroforming can be accomplished using either passive pressurization (forcing sheet metal with a punch into a chamber of water) or active pressurization (forcing sheet metal into a female die using water pressure). Amino Corporation has developed two systems that utilize passive pressurization. The first is the Flexible Production System (FPS) which consists of hydroforming, laser trimming, and piercing and flanging. The second is the Flexible Multi-Forming System (FMFS) which is designed for higher volumes and consists of three press operations: hydroforming, trimming/piercing, and bending.² In both cases, the hydroforming is completed in a chamber designed like a traditional female die. Once the punch completes the down stroke, it hits the female die and thereby performs a re-strike operation. This design helps to minimize the required water pressure and to improve dimensional performance.

² The conventional stamping process includes 5 operations; drawing, trimming, bending, cam trimming and flanging, and cam flanging.

The advantages of hydroforming when compared to traditional stamping include: better surface quality, higher dimensional quality, and increased draw depth. Depending on the draw depth, the typical cycle time for the hydroforming operation is between 1.5 and 2 strokes per minute. FPS is designed for volumes of approximately 10,000 units per year while the FMFS is designed for 10,000 to 40,000.

Toyota utilized FPS in the Sera program (produced for the Japanese market) for volumes of approximately 1,000 units per month. According to Amino, tooling costs were reduced by 65% over conventional systems and piece costs were reduced by 18% (labor and material were higher for the hydroforming process). At higher volumes, hydroforming seems best suited when certain part features are required such as deep draw or high surface quality. The system has been in use in Japan for several years. Amino has recently begun part production in North America for General Motors' Kappa-based Pontiac Solstice and the upcoming Saturn Sky. In addition, hydroforming will be used to make the fender for the Pontiac Grand Prix GXP at volumes approaching 15,000 panels per year.

E. Aluminum Molds

Historically, aluminum molds were restricted to the production of prototype parts due to the limited life of the tool. However, the development of new aluminum alloys such as Alumold now allows for significantly longer production runs than traditional aluminum molds. Processes designed for these molds result in shorter time to market and lower tooling costs. Engineering changes on these molds are also cheaper than comparable steel molds as aluminum is much easier to engineer, leading to fewer labor hours. These molds and processes can be applied to injection or compression molds.

The total number of shots for these Alumolds can be up to 20,000. Also, the die cost is lower if fewer parts are required. Aluminum molds also have the inherent advantage of lower cycle times due to faster cooling. For example, a bumper created on an aluminum mold may have a 30% faster cooling time than if it were produced on a steel mold. However, the increased changeover time associated with low-volume production may reduce the benefits of lower cycle times.

Table 4 illustrates potential cost and time savings presented by aluminum molds. The data, from Paragon Die and Engineering, shows that the molds may enable the low end of the low-volume range, but still may not have the durability for the higher segment of the targeted volume range.

Table 4 – Aluminum Molds: Cost and Time to Market Reductions

Type	# of Parts	Cost of Mold [In % of Steel Mold]	Speed to Market [Weeks]
P20 Steel Mold	500,000		10
LV Al Mold	5,000 to 20,000	70%	8
LV Al Mold (less content)	1,000 to 5,000	60%	6
Prototype Al Mold	<500	50%	7
Source: Paragon Die and Engineering, Grand Rapids			

F. Laminated Tools

Laminate tooling is constructed by producing and stacking thin sections of steel or aluminum that have been laser cut and punched conforming to the geometry of the part being produced. This technology was initially developed for molds, as it allows for faster cooling and shorter cycle times due to the conformal cooling channels designed and built into each tool; however, the technology can also be used to build dies at lower costs than traditional methods. The basic steps in producing a laminated tool are: prepare the math data of the mold/die; laser cut and punch the steel or aluminum plates to part geometry; stack, locate and bond plates; and finish machine surface to net shape, if needed. The problem of sheet stock thickness variation has been solved by measuring the thickness of the plates in the build process, and (in real time) modifying the math data and slice files. Sections can be bonded several ways depending on the application, ranging from epoxy for low pressure tooling to alloy infiltration for applications where high tensile and shear strength is required.

The improved thermal management properties of conformal cooling in laminate molds can significantly lower cycle times, in some cases by up to 50 percent. Laminate tools can also be cut in one day, although the bonding process may take longer. The major cost savings stem from the molding process where piece price savings range from 5 to 20 percent. This technology is already being applied to a variety of molding processes, and production dies, currently in use today.

G. Quick Plastic Forming

General Motors' application of super plastic forming technology, referred to as quick plastic forming (QPF), enables more complex forms from production tooling, thus allowing greater flexibility in terms of shape or part integration. With QPF, a heated aluminum sheet is subjected to high-pressure air that makes it conform to the shape of a hot tool. The high temperature improves the formability so that complex shapes can be manufactured. On the General Motors Malibu Maxx the lift gate, for example, is made from one piece using QPF, and it would have required two pieces without it. The manufacturing process is more stable because the heated parts spring back less than if they were formed conventionally. At General Motors, QPF was developed from a hot blow forming aluminum process used in aerospace. This technology is used in North America on the Chevrolet Malibu Maxx, Cadillac STS, and Ford GT.

H. Roll Forming

Roll forming technology has been utilized for several years in limited automotive application. Historically, these applications have included small structural components and larger, relatively flat, sheet components. However, roll forming presents an interesting technology for low-volume vehicles—especially if the program includes a space-frame design. Although cost and weight advantages may be possible by incorporating roll formed structural components—for example

roof bows, or windshield frames—into an existing unibody platform, the technology may present its greatest potential for cost and weight savings if included as an integral part of a spaceframe design.

Pullman has further developed roll forming technology and combined it with heat treatment in a process dubbed P-Tech. The P-Tech process consists of the following steps: cold rolled steel is rolled, welded, heated, formed, and then quenched. Holes are pierced before roll forming which does not affect the dimensional accuracy of the hole diameter. The process can also shape boron steel and convert it to martensite. The P-Tech process allows for: elongation of up to 50%, more sweep than any traditional roll forming process, tailored profile with varying cross-sections and zero spring back.

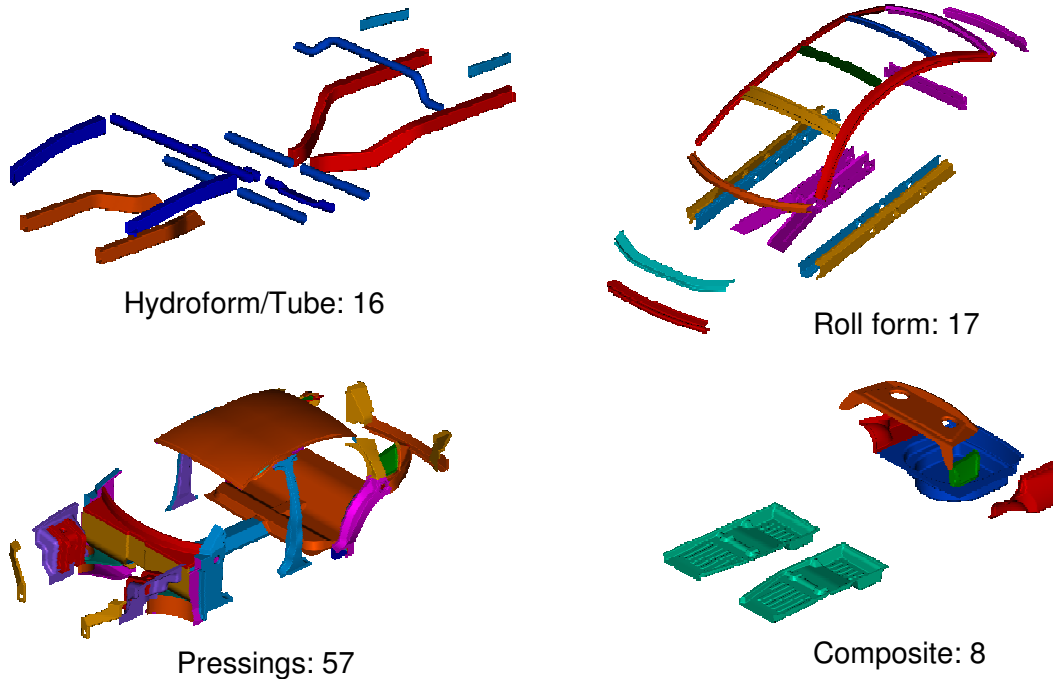
Parts can be produced at 35 feet per minute and laser cutting is possible, especially for low-volume vehicles. The process can replace stamped parts for many non-visible components, although class 'A' surface parts are possible but require more effort. Like traditional roll formed parts, the materials can be easily spot welded.

Cost savings stem from the flexibility of the machines as they can manufacture several components, whereas stamping and hydroforming may require totally separate tools. Pullman estimates that roll forming can reduce the weight of a spaceframe by up to 30 percent when roll formed parts replace those traditionally stamped. The process is currently being used by Ford to create front and rear bumpers for the Mustang as well as several other OEMs.

Dana has presented a case study of a low-volume body structure for unique niche vehicles which incorporates roll forming as an integral part of the structure. According to Dana, the key to delivering low-volume vehicles is to develop the capability to produce low cost and low investment body structures—the spaceframe. Their model illustrates a potential pathway to manufacture multiple low-volume variants from the same manufacturing infrastructure, while requiring a minimal amount of dedicated tooling and body shop floor space.

The Dana study incorporates roll forming as an integral part of the structure. F.A.S.T concept is a hybrid spaceframe construction composed of 16 hydroform/tube components, 17 roll formed components, 57 pressings, and eight composite components (Figure 25). In the case study, the completed underbody is delivered as a completed model. The spaceframe is then assembled using built-up modules in a six station body assembly line.

Figure 25 – Dana Fast Car



I. Lean Dies

Lean stamping dies are often used by Japanese OEMs for cost reduction. Different companies have significantly different strategies for lean die production but there are several common aspects. Critical to this concept is the minimization of component complexity—that is, machine complex shapes through hydroforming, roll forming, etc. leaving the conventional dies as straightforward as possible. Second, die design depends more on preventative maintenance and less upon a “built to last” mentality. This allows for simpler and more cost effective designs. Third is the ability to synchronize tool manufacturing with product design, resulting in a construction process that is more automated and faster than many current practices. Finally, the procedure to accept dies at tryout is best utilized in a functional build environment concerned with getting a subassembly that has very high dimensional accuracy without focusing on getting each component from each die perfect.

Benchmark studies have indicated up to a 3 to 1 cost advantage by using the Asian lean tool strategy. The best of the Asian OEM’s at tool cost minimization achieve their press tooling for a car body at about 33 percent the cost of a typical North American company. This difference is probably the same or more when compared with many German tools. Although the total cost differential is not practical to eliminate because of important differences in business and product

strategies, there are aspects of the lean tool strategy that can be employed. On the negative side of the lean tools, higher operating costs are realized because of increased production maintenance and vulnerability to tooling damage. Leaner tools mandate a higher level of preventive maintenance in the press shop for both presses and tools.

J. Tandem Molds

Tandem molds are used to make two parts in two separate cavities using a specially designed mold. This process was originally designed to meet the cost constraints of low-volume parts. By producing parts in tandem, it increases the output of the mold machine. The savings is in cooling time, and mold changeover. The added cost of the Tandem mold is slightly higher than the cost of the second set of molds that would otherwise be required. Such a strategy can be especially effective for family parts (e.g., right and left parts). They do not require special machinery, thus can be used on standard horizontal presses.

K. Direct Metal Technologies

Direct Metal Technology (DMT) involves applying metal powder to a controlled area and melting the powder with a laser. The result is a hardened surface that has applications in reconfiguring old tools, converting prototype tools into low-volume tools, restoring worn parts and die servicing. This technology, originally developed at the University of Michigan, works with a wide variety of metals used in the manufacturing process.

The wide range of capabilities from DMT makes it difficult to construct a general business case analysis; however, several benefits can be expected. First, the elimination of soft tools is feasible due to the rapid fabrication of low-volume tools. Existing soft tools will become re-usable by adding a hardened layer of metal to their surfaces. Finally, tooling lead-time will be greatly reduced by up to 50 percent.

L. Flexible Hemming (Roller Hemming)

Flexible hemming systems using robotic cells offer opportunity to lower the cost of low-volume body-in-white assembly. Roller hemming utilizes a flexible robotic cell to complete closure panels for doors, hoods, lift gates and other similar sheet metal assemblies. The robot's end-effector is equipped with a roll that bends a flange in order to create a hem. This is done by moving the roll at an angle along the flange in several cycles. Roller hemming can eliminate the need for hemming dies. The drastic reduction in the price of flexible robotics in recent years has made roller hemming an even more cost attractive solution.

The roller hemming cell can be a rather simplistic operation, with relative low cost, or it can be a more complex combination capable of hemming several components. In its most simple form, roller hemming can enable cost effective manufacture of very low-volume panels. For example, a roller hemming system has effectively been used to assemble prototype parts. Audi also uses roller

hemming for selected aluminum closure panels on the A8. As might be expected, the Audi roller hemming system presents a very capital intensive solution. Utica Tooling offers a more complex roller hemming operation, capable of producing several door, hood or deck lid variants at up to 90 products per hour.

M. Multi-Spindle Machining Center

The multi-spindle machining center is a specialized system that allows for efficient machining for a variety of parts, such as parts for chassis, transmissions housings, common rails, pumps, fittings, hydraulics and electric motors. The machining center has at least four independently controlled spindles that may be used for drilling, milling, threading, phasing or turning. The machine also includes a 5-axis work piece holder that can carry up to 16 parts of one family type or up to 4 different families. The center is designed to be used by a single operator. It replaces capital intensive and dedicated transfer lines. In one example, a supplier previously made a knuckle for a suspension assembly in a transfer line which consisted of several stations and multiple fixtures. The cycle time in this process was about 17 minutes. This production line was replaced by a single machining center, in which the part is machined in a single fixture in four minutes.

VI. Conclusions (and Next Steps)

CAR believes there are numerous lessons learned from this research project. The following is a brief description of those conclusions:

First, the outlook for low-volume is unclear with respect to how low the volumes (per model) will go, how differentiated the models will become, and whether or not OEMs can cost effectively (profitably) produce these vehicles at high volume prices. However, the trend is clearly heading in this direction and most OEMs are well down the path of implementing flexible body shops to compete in this market. Some OEMs will continue to have difficulty as volumes continue to decline, and this opens up opportunities for suppliers of tools, parts, materials, assembly, and engineering. One of the future objectives of this project will be to better develop the business case for the opportunity for suppliers.

Second, low-volume vehicles are producing a “technology pull” for new materials and processes. Materials and processes with inherently lower investment costs (but often higher variable costs) become more viable at low-volume production. Many candidate technologies need further development before they can be deployed on programs with acceptable technology risk. This project proposes further identification of the economic performance, risk profile, and additional development that these technologies require before they can be used in low-volume production.

Finally, many automotive suppliers wish to support low-volume production but do not know how to position themselves. There are numerous pathways to achieve low-volume and each pathway results in a different business model for supplier involvement. This project will further define these pathways and help suppliers identify where they fit most competitively in the supply chain.

Next Steps: after discussions with industry stakeholders, CAR has identified at least three possible avenues for future research. It is important to note that these are in the developmental stage. Suggestions for refinement and/or new directions are welcome. The proposed research directions are:

A rigorous cost model of integrator developed and manufactured low-volume vehicles. CAR believes it is ideally positioned to lead a team of industry participants in creating unbiased business cases for the development of low-volume vehicles. Such a program would leverage the knowledge of the industry participants, with the neutral analysis of CAR and our partners to create cost models for the manufacture of low-volume vehicles. CAR would then validate the models with OEMs and present the results for broad dissemination.

A consortium (likely including an integrator, and key module and tooling suppliers) working together to bid on low-volume vehicle opportunities. This group would leverage low-cost development, tooling and component strategies to deliver high-quality, low-cost vehicles in a timely manner.

Create a consortium of stakeholders to develop a viable post production alteration—or SEMA pathway for low-volume vehicles. Based on response from the SEMA workshop, CAR believes this consortium could serve a critical need in this segment.

The creation of a pre-competitive consortium of integrators and tier 1 suppliers to serve as a focal point for the development and promotion of pre-competitive low-volume pathways. Such an organization could use USCAR as the model, with development work on processes that would enable low cost low-volume techniques.

VII. Appendix: Low-Volume Manufacturing Technologies

The investigation into technologies for part fabrication tooling was conducted using the template below. Although it was the goal to get information for each item in the template, it was either not always possible to obtain complete information. The following is a template for data collection on low-volume part fabrication tooling technologies:

Description

- Purpose
- Process steps
- System requirements
- Technology origin
- Technology developer

Performance

- Cycle time
- Tool life
- Part quality
- Tool maintenance requirements

Business Case

- Lead time for development
- Investment cost
- Piece cost (labor, material, etc.)
- Salvage

State of Readiness

- Current status
- Expected introduction
- Risk assessment

A. Shell Tooling Technology

Description

- Shell tooling consists of a metallic shell that is backfilled to generate a die. The steps to produce a shell are:
 - A modeling board is generated from CAD data.
 - A negative of the modeling board is cast.
 - A shell is made by applying hydrostatic pressure onto a heated metallic sheet (to press it against the castable mold) and removed.
- The shell is made out of an aircraft grade alloy, which is used in aerospace. A gage of 2mm is used for most applications but it may vary depending on the application. Any medium (e.g., aluminum, cast iron or kirk-site) can be used to “backfill” the shell once the metallic shell is

removed from the mold. The selection depends on the task and the tool maker's preference.

- Features for actuators, cams, cooling lines, and brackets can be incorporated into the dies. The process also eliminates the need for post-machining.
- The shell may be used for the drawing operation in any kind of die (line die, progressive die, etc.). It is expected to be capable of withstanding the most demanding stamping and forming processes, such as, for high volume production.
- Compared to traditional stamping dies, there are no known restrictions on the part geometry that can be formed with this technology. The shell can also be polished to achieve the finish that is required of class 'A' panel parts.
- The maximum size of the shell is 5' x 10'. This restriction is due to the available press in the shell production process.

Performance

- The shell production process is robust against material shrinkage as the metallic sheet is reshaped and the molecular structure remains unchanged.
- The dies will have to be tested in the production environment to assess their durability.
- Preliminary experiments have shown that the material used for the shell tooling is weldable and machinable. Hence, dies with shell tooling technology are expected to be as maintainable as regular dies.
- Weldability and machinability also depend on the thickness of the shell. They might vary depending on the feature or if machining is expected to be necessary in certain areas.

Business Case

- The gain from shell tooling increases with the size and complexity of the part. When designing larger dies, savings in labor cost outweighs the increase in material cost.
- Depending on size and complexity of the die, total tool cost (punch & die) reduction can be up to 30% compared to conventional steel tooling. It requires approximately 4-6 weeks to make the shell tool. This means that the lead-time to deliver the tool may be reduced by 35% to 45% compared to processes with traditional construction methods.
- Spirit AeroSystems has partnered with two major die shops in the North American automotive industry—Richard Tool & Die, (www.rtdcorp.com), and Sekely, (www.sekely.com)—to develop and market this technology.
- Stamping applications include hard metallic surfaces, matched tooling, complex geometry parts, and multiple wear surface coatings.
- The technology is also applicable to hydroforming under high pressure, and multiple stage forming.

State of Readiness

- The two die shops that will help in the commercialization of the technology have used dies with shells in test runs. One shell was used in a draw die for wheel houses and another die was used in the progressive die for a stiffener element.
- The first production application in a progressive die with a planned volume of 5,500 parts per week will launch soon.

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Figure 26 – Punch in Progressive Die

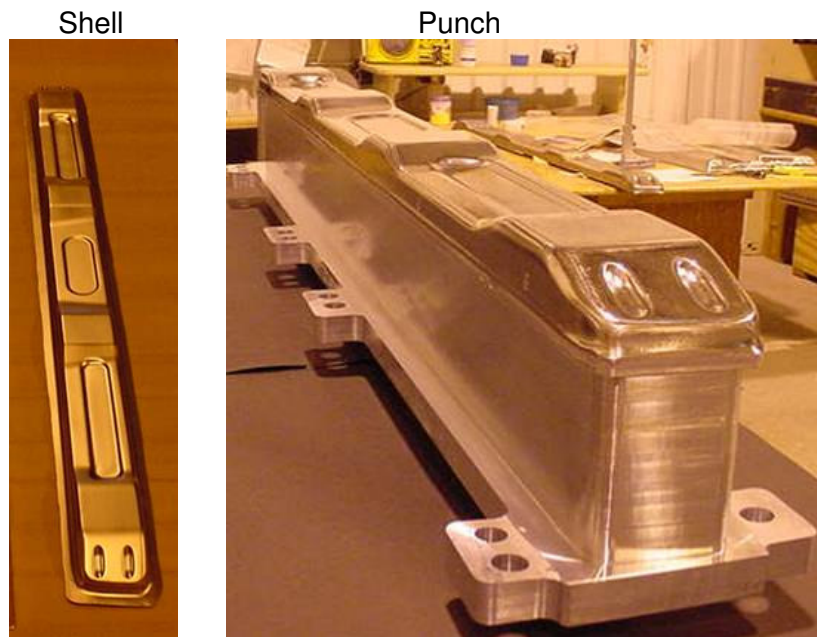


Figure 27 – Punch



B. Liquid Impact Forming

Description

- Liquid impact forming (LIF), a development of Greenville Tool & Die (www.gtd.com), bridges the gap between traditional hydroforming and tube, pipe and stretch bending.
- This works by submerging and filling a pre-bent metal tube with a lubricating compound, and then stamping with 5,000-30,000 psi. It is essentially a type of crash-forming operation where the fluid inside the pipe serves to build counter pressure in the forming operation.
- The fluid is not injected into the tube, but the tube is filled as it is submerged into the die.
- The tube is sealed with end caps to maintain atmospheric pressure.
- During stamping, the hydraulic pressure is mechanically released.
- LIF can be performed in existing stamping presses.

Figure 28 – Die Before Forming

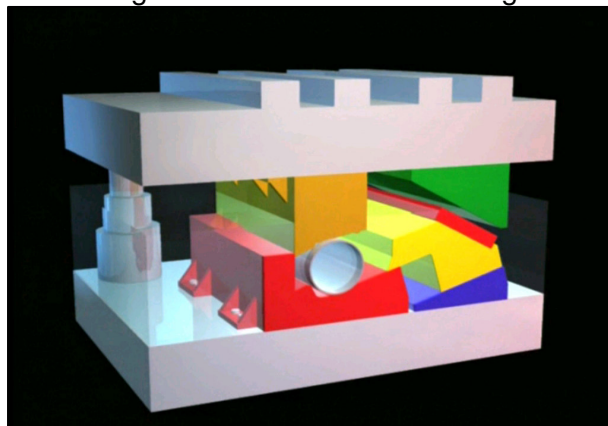
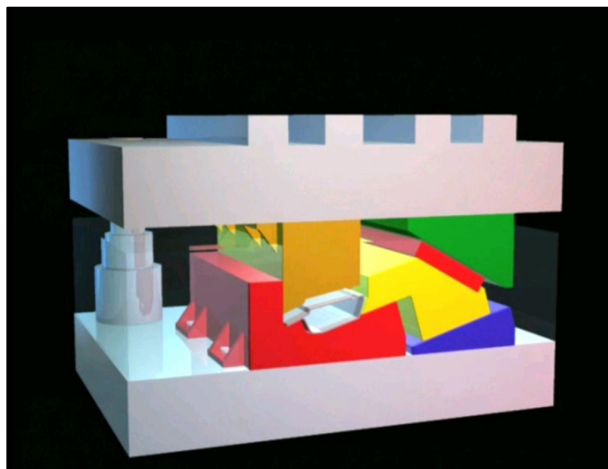


Figure 29 – Die After Forming



- It can hold tolerances of ± 0.25 mm.
- It can form a variety of materials.
- LIF can produce 450-500 parts per hour; 2.5 times more productivity than traditional hydroforming.
- The process allows for severe section changes, embossing and sharp radii (bend to 150°). Parts can also be flanged in the LIF operation.
- The technology seems most suitable for making roof supports, A-pillars, and other structural frame parts.

Business Case

- Savings are in production rates, reduced welding and the ability to flange in press.
- Production in stamping press might allow for up to 200% in savings (when parts are eliminated).

State of Readiness

- This technology is still being developed. Successful tests have been conducted for a variety of materials (e.g., DP600 and 8mm aluminum tubes.)
- The next stage is the testing of dies in the production environment.

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C. Hydroforming (Sheet)

Description

- In general, sheet hydroforming is performed by forcing sheet metal with a punch into a chamber of water (passive pressurization) or by forcing sheet metal with water pressure into a female die (active pressurization).
- Amino (www.amino.co.jp) has built two systems around the hydroforming operation
- The Flexible Production System (FPS) consists of hydroforming, laser trimming, piercing and flanging.
- The more recent Flexible Multi-Forming System is for higher volumes and it consists of three press operations: hydroforming, trimming/piercing and bending.
- The Amino system works with passive pressurization, where the water chamber is largely designed like a traditional female die. Once the punch completes the down-stroke, it hits the female die and thereby performs a restrike operation. This design helps to minimize the required water pressure (or binder force) and to improve dimensional performance.
- Hydroforming is normally used for low-volume applications.

Performance

- There are possible advantages of sheet hydroforming over stamping
- It has better surface quality
- It has a higher dimensional quality
- It has increased draw depth
- It is cost-competitive in low-volume (e.g., investment and piece cost)
- Depending on the draw depth, the typical cycle time for the hydroforming operation is between 1.5 to 2 strokes per minute.
- FPS has been used by Toyota on small volume vehicles. It is designed for volumes around 10,000 units per year. The more automated Flexible Multi-Forming System is designed for higher volumes of up to 40,000 units per year.

Business Case

- In the Toyota Sera program, FPS showed the following benefits (at volumes of 1,000 vehicles per month):
 - a reduction in tooling cost by 65% over conventional systems, and
 - a reduction in piece cost by 18% over conventional systems
- At higher volumes of up to 50,000 panels, sheet hydroforming seems most suited if certain part features are required, (e.g., deep draw, high surface quality or high dimensional quality).

State of Readiness

- Hydroforming has been used on several programs in Japan. The first two hydroforming production lines in North America are currently being

installed at Amino in St. Thomas, Ontario and at GM in Pontiac, Michigan. Both lines will support GM's Kappa platform as well as other niche vehicles (e.g., Pontiac Grand Prix GXP).

- Amino will produce sixteen sheet hydroformed parts for the Kappa platform (Solstice and Saturn Sky) at a volume of 25,000 panels per part per year. Production for the Solstice will start in April of 2005. In addition, they will also make the fender for the Pontiac Grand Prix GXP at 14,000 panels per year.

Figure 30 – Flexible Production System

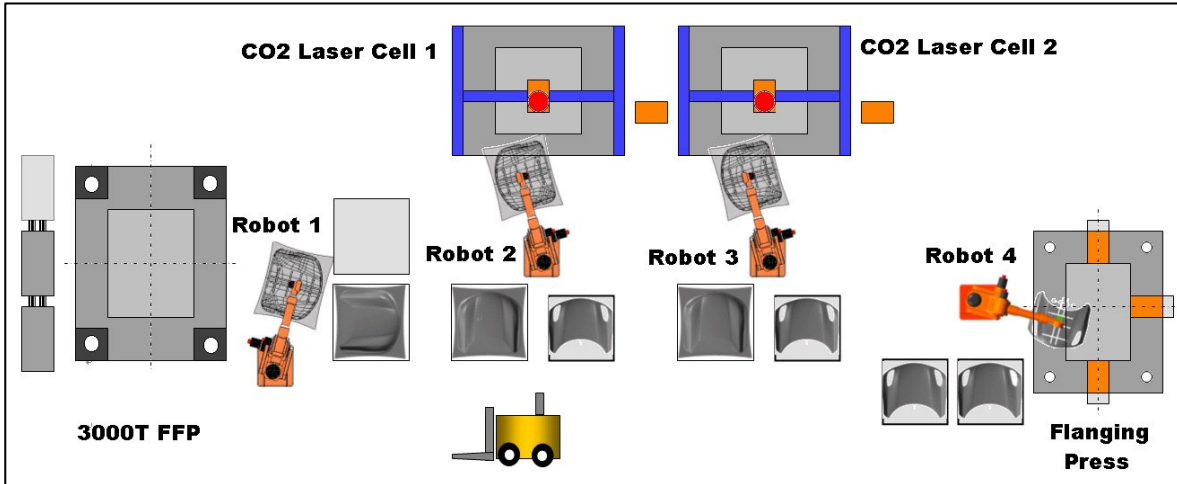


Figure 31 – Flexible Multi-Forming System

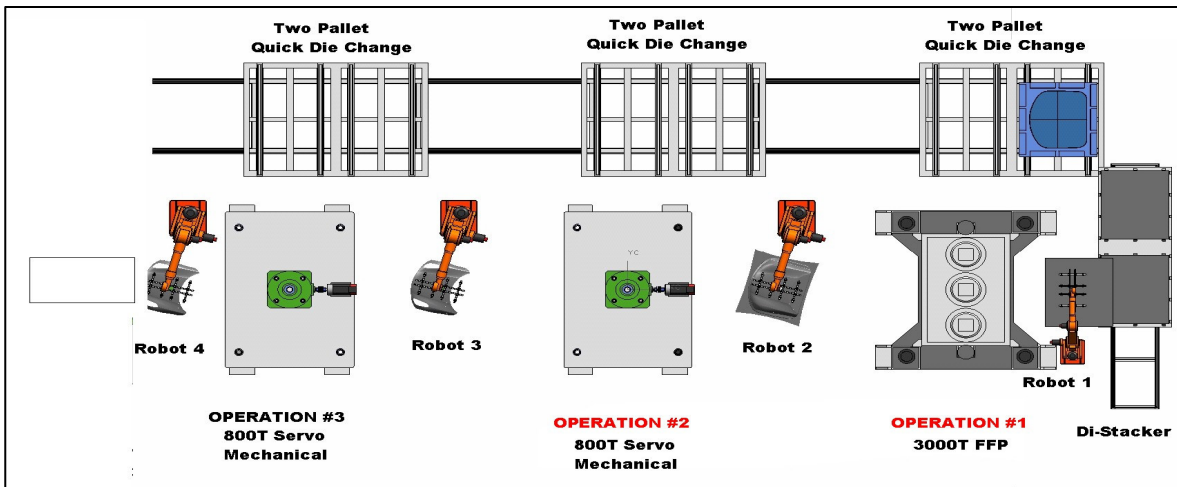


Figure 32 – Pontiac Grand Prix GXP



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D. Aluminum Molds

Description

- Molds made from aluminum were usually limited to the production of prototype parts, as the life of the tool did not allow for higher volumes. The development of new aluminum alloys, such as Alumold, now allow for significantly longer runs on aluminum molds.
- A process that is designed around these new materials allows for shorter time to market and for tooling cost reduction.
- Engineering changes on these molds are also cheaper than for those with conventional steel as aluminum is easier to machine than steel, leading to fewer labor hours.
- The process can be applied to injection or compression molds.

Operating Parameters

- The number of total shots can be up to 20,000. The die cost is lower if fewer parts are required.
- The inherent advantage of aluminum molds is faster cycle time due to faster cooling. For example, a bumper that is molded on an aluminum mold might have a 30% faster cooling time than the same process on a steel mold.
- The increased changeover time due to low-volume runs might reduce the benefit of lower cycle times.

Business Case Example

- An actual example from Paragon Die & Engineering, (www.paragondie.com) of the relative cost of aluminum molds for making fascias when utilizing the material's full potential is presented in Table 4, Page 64.

State of Readiness/ Application

- Aluminum tools from these materials are already in production.

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E. Laminated Tools

1. Laminated Tooling

Description

- Laminate tools are built by producing and stacking thin two-dimensional sections of steel and aluminum. This technology was initially used for molds as it provides conformal cooling for faster cooling and shorter cycle times. The technology can also be used to build dies at lower cost.
- Process description:
 - Prepare math data (3D model) of mold/die
 - Laser cut steel/aluminum plates
 - Stack, measure and join parts
 - Machine surface to net shape, if needed
- Fast 4M, (www.fast4m.com) also solved the problem of variation stack-up due to sheet thickness inconsistencies by designing a close-loop measuring system. This system measures the thickness of the dies every time after x number of sections are produced. Before producing the remaining sections, the 3D model is updated to compensate for the variation in the production of the next x sections.
- Sections can be bonded in various ways, depending on the application. Epoxy might be used for low-pressure tooling such as vacuum molds, foam molds, RIM tooling, etc. Brazing might be used for high-strength high-temperature molding applications, and alloy infiltration might be used for applications where high-tensile strength is needed (e.g., for injection and stamping dies.) Laminate tools that are bonded using alloy infiltration have 92% to 94% of the tensile and shear strength of an equivalent wrought block of steel.
- This technology can be applied to dies and molds.
- Materials for laminate tools can be aluminum, steel, stainless steel, etc.
- For molds, it enhances options for thermal management as cooling channels can be designed in any way desired. This reduces residual stress and warp in the part and reduces cycle time of the operation.
- The technology for laminate tools can be combined with other technologies, such as deposition technologies, to achieve desired surface properties.

Performance

- There are several molds in production now and total tooling life is still being investigated.
- Better thermal management allows for shorter cycle time for molds. For some parts, cycle time can be cut in half.
- Laminate tools can be cut in one day (bonding might take several days).

Business Case

- For molding, part cost savings are estimated to range from 5% to 20%, depending on the application. Cycle time can be reduced 20 to 50% as the cooling time is lower than that for conventionally designed molds.

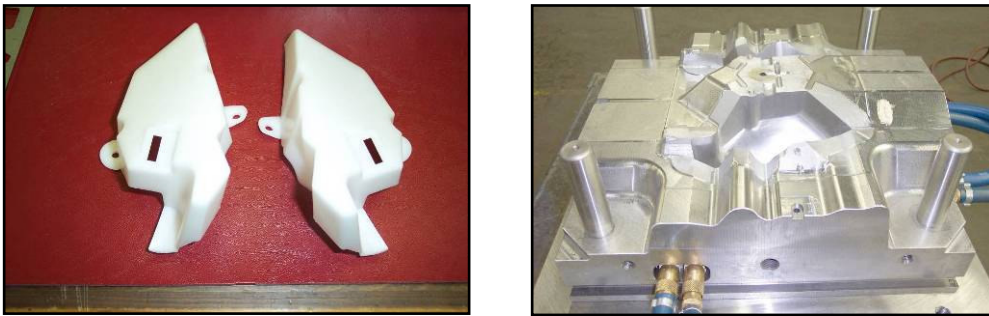
State of Readiness

- Technology is already applied to molds.
- Production dies are currently being developed by this company.

Example 1: Injection Mold Tool for Airbag Housing

- Stainless Steel tool built in 2002
- 150,000 - 175,000 shots
- Cycle time reduction of 20 to 30%

Figure 33 – Laminated Airbag Mold



Example 2: Mold for Seat Foam

- Lightweight Aluminum tool built in 2003
- 10-day build time
- Currently running in production
- 130,000 shots to date

Figure 34 – Laminated Mold



Figure 35 – Laminated Door Panel for Dodge Viper



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2. Sekisou Laminated Tooling

Figure 36 – Laminated Die (Before Final Machining) and Drawn Part



Description

- Laminate tools are also made by companies in Japan and Europe. Sekisou Tooling (www.sekisou.com) is a Japanese company which makes molds and production dies. It uses 3D models of the die to determine the contour of each layer of sheet metal. After the layers are laser cut, the die or mold is built by stacking and connecting the individual layers and by machining the die surface.
- The layers are aligned horizontally and datum pins and holes are used for proper alignment. Variation stack-up is controlled in the last operation, when the excess material is removed in a machining operation.

Performance

- Sekisou's laminated dies and molds are designed for mass production systems.

Business Case

- The general advantages for dies are shorter lead time and reduced manufacturing costs.
- For some cases, the lead time to make a die can be cut in half at 70% of the cost.

State of Readiness

- Production of these dies started last year and 20 tools have been built.

Example for Production Die

- Panel for motorcycle gas tank
- So far, 200,000 panels made with this die
- Lead time reduced by 50% over conventional tooling
- Cost reduced by 30% over conventional tooling

Figure 37 – Example for Motorcycle Tank



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F. Quick Plastic Forming

Description

General Motors' application of the super plastic forming technology referred to as Quick Plastic Forming (QPF), enables more complex forms from production tooling, thus allowing greater flexibility in terms of shape or part integration. With QPF, a heated aluminum sheet is subjected to high-pressure air that makes it conform to the shape of a hot tool. The high temperature improves the formability so that complex shapes can be manufactured. On the General Motors Malibu Maxx, the lift gate (for example) is made from one piece using QPF. It would have required two pieces without it. The manufacturing process is more stable because the heated parts spring back less than if they were formed conventionally. At General Motors, QPF was developed from a hot blow-forming aluminum process used in aerospace. This technology is used in North America on:

Figure 38 – 2005 Chevrolet Malibu Maxx Lift Gate



Contact Information:

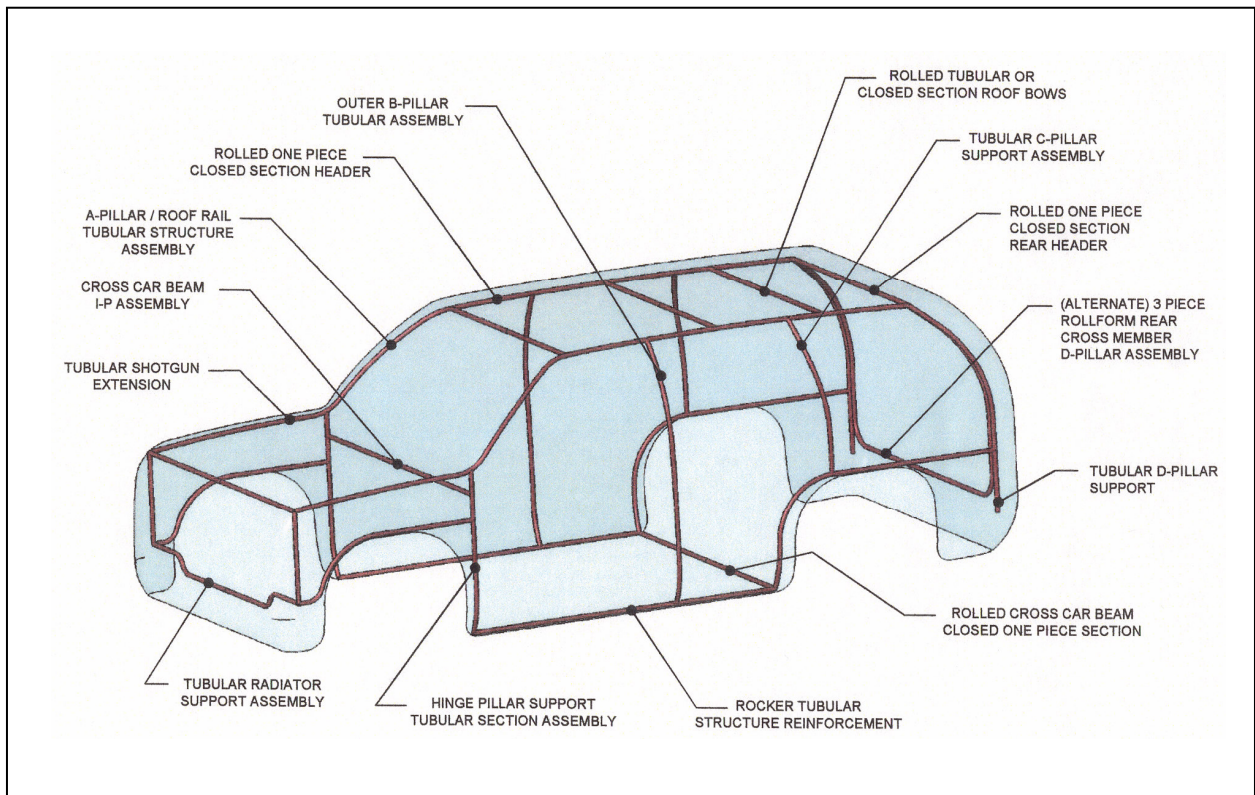
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G. Roll-Forming

Description

- Pullmann, (www.pullmanind.com) has further developed the roll forming technology and combined it with heat treatment.
- The P-Tech process is done in the following steps: Cold rolled steel is rolled, welded, heated, formed and quenched.
- Holes are pierced before roll forming, a process which does not affect dimensional accuracy on the hole diameter as it is well controlled. (The quality on the hole diameter is very high.)
- The P-Tech process can shape boron steel and convert it to martensite.
- The process allows for:
 - elongation of up to 50%,
 - more sweep than any traditional roll forming process,
 - tailored profile with varying cross sections, and
 - “zero” spring back.

Figure 39 – Roll-formed Spaceframe



Operating Parameters

- Parts can be made at 35 feet per minute.
- Laser cutting is an option, especially for low-volume.
- Replacement of stamped parts is easier for non-visible parts. Class A surface parts can be made but require more effort.
- Roll-formed parts and materials can be easily spot-welded.

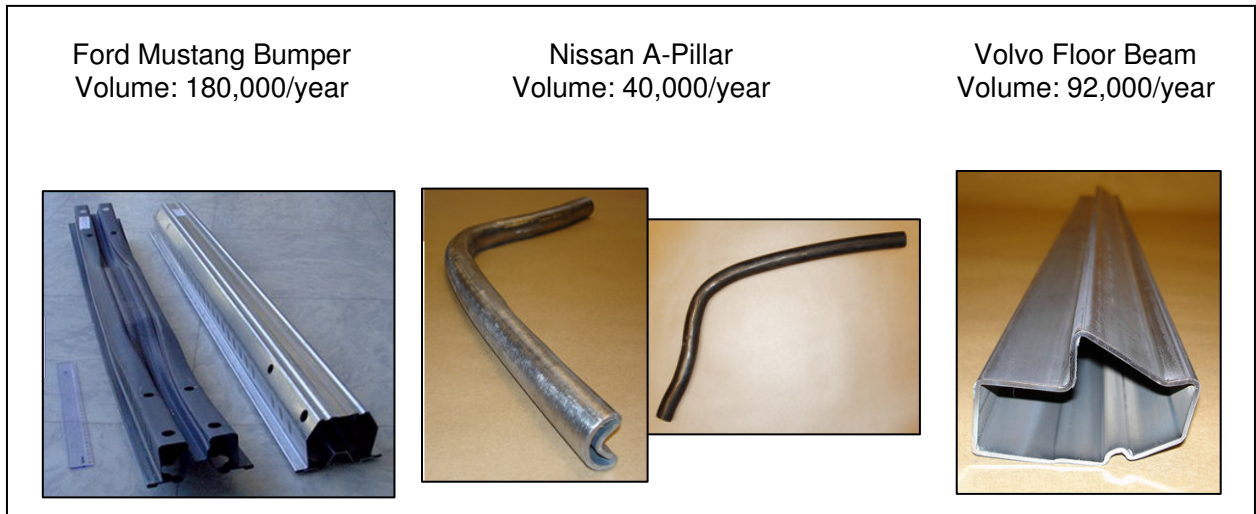
Example for Business Case

- Roll forming can be used to make several parts: e.g., the rocker panel, roof rail, header, and bumper.
- Roll-forming tools are relatively inexpensive.
- Parts with similar profiles can be made on the same tool, reducing the number of tools needed (compared to stamping and hydroforming). This effect can be enhanced by making parts with similar profiles across several vehicles on the same tool.
- Example: 3 roll tools can make 14 parts, which may save up to \$10 million.
- A business case can also be made for the design of a spaceframe with roll-formed parts. The advantage over a hydroformed spaceframe is the low investment cost of roll-forming tools and the limited number of tools needed for the production of roll-formed spaceframe parts.
- For increased safety requirements, martensite/UHSS parts will have to be incorporated into a safety cage (e.g., rocker panel and roof rails). Some of those parts might be cheaper as roll-formed parts.
- Pullman estimates that roll-forming can reduce the weight by 30% when substituting hydroformed parts.

State of Readiness/Current Applications

- A prerequisite to maximize the benefit is to design parts for roll-forming within and across vehicles.
- An upcoming application for parts made on the P-Tech process is the front and rear bumpers for the Ford Mustang (185,000 units).

Figure 40 – Current P-Tech Applications



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H. Lean Dies

Description

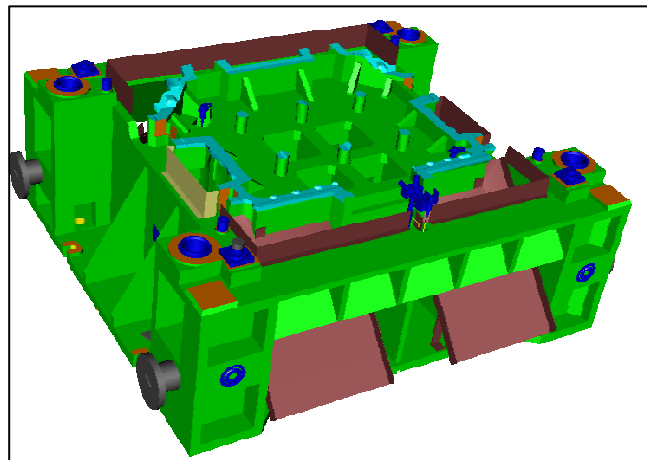
A key strategy for tooling cost reduction (often observed with several Asian OEMs) involves the design and construction of lean stamping dies. Different companies have significantly different strategies with lean dies, so the following description is general. The definition of lean dies entails several different aspects, including:

- Part design (component complexity) – simplifying part design so that the tools are easier to design and construct. Using Asian parts that are sometimes smaller and less complex (e.g., less depth of draw) than comparable North American parts. Commonality across part designs also contributes to fewer engineering changes that may be required later. New advanced forming techniques (such as roll-forming, hydroforming, and hot-forming, etc.) can be used for complex shapes/materials leaving conventional dies for more straightforward part designs. Advanced engineering tools (e.g., formability analysis, spring-back prediction, and 3-D solids design) contribute to standardized and predictable tool performance, thus reducing uncertainty and the need for future engineering changes or tooling delays.
- Die design (die standards) – many of North American tooling designs have their roots in European (German) practices, and are “made to last” with minimal maintenance. By Japanese tooling standards, North American (and most European) tools are seen as “over-engineered” and overly complex. Many Japanese tools are seen as fragile (e.g., less reinforced base), simpler (fewer cams and complex forming operations), and have less critical surfaces (e.g., less bearing surface). There are examples where Asian tools (for comparable parts) can be as much as 50% lighter in mass. Because of the huge opportunity for cost reduction with lean dies, the North American companies are cautiously exploring how to exploit this technology. Specific considerations include, for example:
 - Reducing die mass by 50% through casting relief
 - Reducing the number of die components (cylinders, cams, etc.)
 - Reducing the punch finishing (which also reduces tryout, casting costs and machine time)
 - Fewer hardened inserts and more flame-hardened surfaces
 - Elimination of double wear plates
 - Improved design to simplify gaging (eliminate flipper gages)
 - Matching the die to the part, rather than the part to the die, thus resulting in smaller tools and tools that are suited to the anticipated level of production
 - Less tool finishing on non-show part areas of the die
- Construction (manufacturing) – a key result of standardized product design is the ability to synchronize tool manufacturing with product

design, resulting in a construction process that is more automated and faster than with new and uncertain tools whose processing times are more unpredictable. Standardized product design leads to standardized tooling construction processes which are faster and more predictable. One North American OEM indicated that their internal tooling making capability (number of dies) has increased 90% over the past five years primarily due to developing standardized tooling construction methods without any increase in tool construction personnel.

- Tryout (procedure to accept dies at tryout)—the functional build perspective taken by most Japanese firms—focuses attention on quickly attaining a subassembly that has very high dimensional quality, without focusing resources on getting each component from each die individually “perfect.” A different strategy is used in developing geometric dimensioning and tolerance assignments (GD&T) with functional build, rather than attempting to minimize all checkpoint tolerances. The functional build tryout method alone can reduce tooling cost by 10% on average (more on complex tools). The savings accrue principally from focusing on cause-and-effect solutions.

Figure 41 – Lean Trim Die



Business Case

Benchmark studies have indicated a cost advantage of up to 3-to-1 by using the Asian lean tool strategy. The Asian OEMs who are the best at tool cost minimization achieve their press tooling for a car body at about 1/3 the cost of a typical North American company. This difference is probably the same (or more) when compared with many German tools. The cost differential significantly accounts for why Asian companies can competitively produce lower-volume vehicles than their North American counterparts. Although the total cost differential is not practical to eliminate because of important differences in business and product strategies, there are aspects of the lean tool strategy that can be employed. On the negative side of the lean tools, higher operating costs are realized due to increased production maintenance and vulnerability to tooling

damage. Leaner tools mandate a higher level of preventive maintenance in the press shop, for both presses and tools.

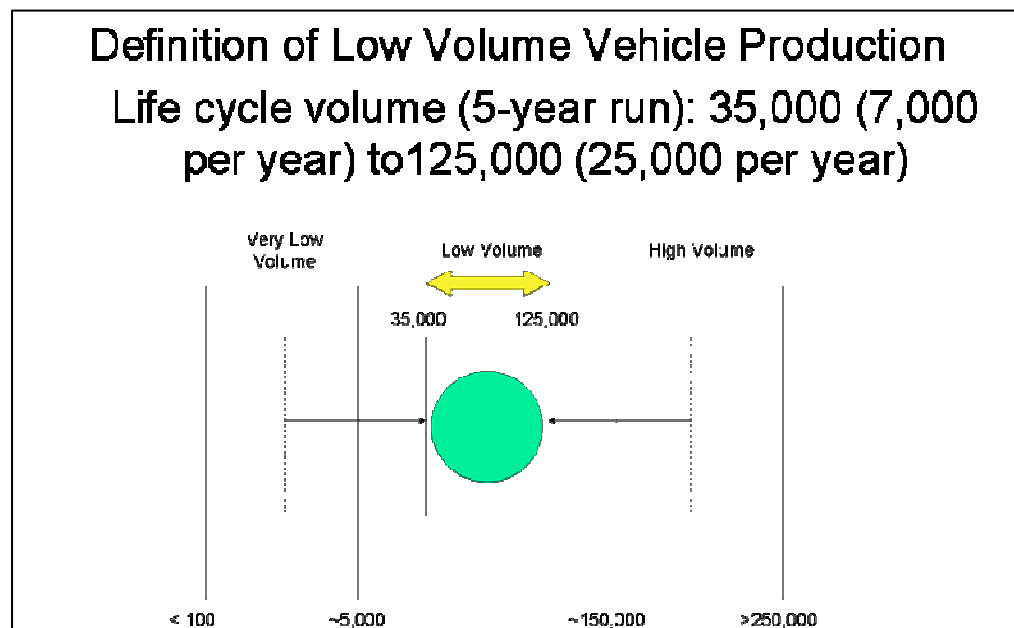
State of Readiness

The cost and lead-time advantage of lean tools is forcing North American companies to evaluate what aspects to use and how to best implement lean tools. The fear of tooling failures in production is restricting speed of implementation much more than the lack of knowing what to do.

Example for North-American Approach to Lean Dies

Several companies are developing tools for low-volume production. One example is the Diversified Tooling Group (<http://www.diversifiedtoolinggroup.com/>), a major supplier of stamping dies to the Midwestern automotive industry. Their definition of low-volume ranges from 25,000 to 125,000 panels for the life of the tool, and their focus is on stamping tools for about 40,000 to 60,000 parts. Concepts for these tools include a variety of ideas. For example, draw dies could be made as red urethane plank dies. This design has been applied to a die for door inner panels, and it can be used to run up to 18,000 parts. Dies may also be constructed with shoes that are made from blocks of steel and that can be used with a variety of dies within a program or across programs. Most of these concepts include the use of laser trimming and hydraulic flanging after the forming operation. The dies and the presses also require additional maintenance, similar to Japanese die concepts.

Figure 42 – Matching Tool Standards with Volume



Example of the North-American Approach to “Low-Cost Competitive” Dies

Low-cost competitive (LCC) tools are made in low-wage countries for North American production. The LCC advantage is low wages. For example, the hourly wage rate in China is about 20 times cheaper than in North America (approximately \$20 vs. \$1 per hour). The challenge with LCC tools is that they often have inferior quality, are difficult to program manage during construction, and require extensive revisions before going into production. (As one customer pointed out, “we know we can buy cheap tools overseas, but we do not know if they will work.”) However, their low-cost appeal has intrigued many North American customers. A so-called, “integrator” model is being encouraged by many North American customers. With this approach, local tool companies will:

- Program manage a tool package and determine what LCCs are capable of producing and what must remain domestic.
- Engineering may also be performed locally or in a foreign country. As one example, Hindustan Motors (India) would perform tool engineering at approximately 50% the rate experienced in North America. They would also help source tools throughout Southeast Asia.
- Implement engineering changes domestically when the tools arrive for tryout. (Some customers have asked that engineering change costs be pre-determined rather than based on time and materials.)
- Provide tool tryout and validation support for final production approval.
- Provide tool maintenance support as needed.

While there are many controversial aspects of this strategy, the appeal of lowering production tooling by 50% is pressing the tooling industry to pursue this approach. Lower-volume vehicles will accelerate this path.

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I. Direct Metal Technologies

Description

The direct metal technology (DMT) is a well established technology that was developed into a production process at the University of Michigan. Precision Optical Manufacturing (POM) spun off from the University and was founded in 1998 (www.pom.net). The DMT metal fabrication process is most effective for the following types of applications:

- Reconfigure old tooling into new tooling
- Produce tooling using bi-metallic tooling technology
- Last minute changes to modify styling
- Convert prototype tooling into low-volume production tooling (by adding a hardened coating to the “soft” tool)
- Restoring worn parts on old tools
- Die servicing – tool repairs
- High productivity injection molding and die casting
- Low-volume laser cut tooling (laminated tools)

The metal deposition process involves the synthesis of metallic powder, typically an iron-based, cobalt-based or nickel-alloy or ceramic-metal composite), transported to the nozzle by an inert gas (Ar or Ar-He mixture) at a pre-defined rate from one of four powder feeders. Metallic powder is added to the melt pool, established by the focused laser beam. The size of the melt pool and its temperature are closely controlled.

POM holds over 30 patents on DMT. POM's laser-based metal fabrication process currently serves several industries, including automotive. A full service tool fabrication facility for the design and development of prototype and production tooling exists in Auburn Hills, Michigan. Metals that can be deposited using DMT include:

- H13 (automotive die casting tooling)
- H19 (magnesium die casting for automotive)
- Anviloy (automotive die casting tooling)
- Aluminum
- P20 (interior, exterior auto trim tooling)
- SS420 (rear lighting tools for automotive)
- S7 (airbag tooling)
- D2 (automotive stamping tooling)
- 17-4
- 15-5 (automotive lens tooling)
- Nickel (door inner panel molding)

Figure 43 – Direct Metal Deposition Process

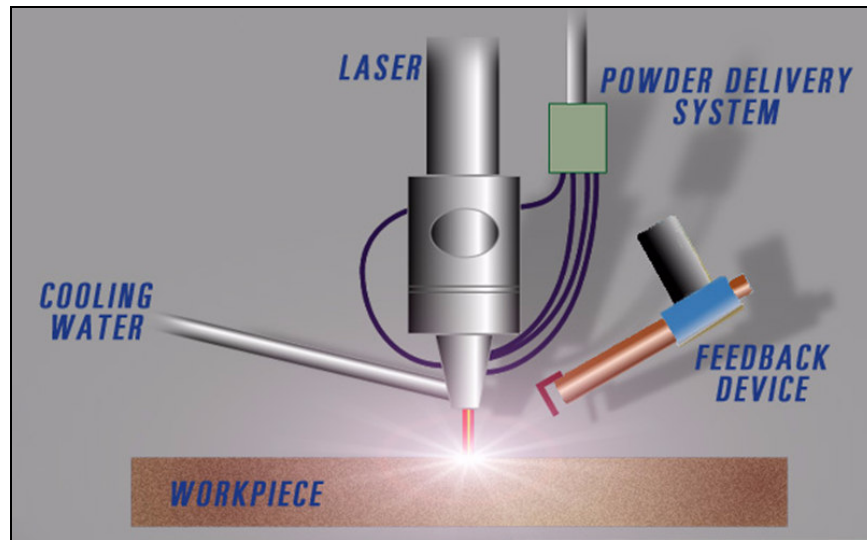


Figure 44 – Laser Deposition Tool Coating



DMT can also be applied to produce laminated tooling for low-volume production. Laminated tooling can be made from laser cut sheets and then coated using DMT. This process develops a “hard face” on the tooling surface and can be applied to both molds and dies.

Figure 45 – Conformal Cooling Tool for Fiat and First Shot (CRF)



Business Case

The broad range of capabilities of DMT makes it difficult to construct a general business case analysis. Generally, the following benefits can be expected:

- Elimination of “soft” tools, feasible due to the rapid fabrication of low-volume tools.
- Re-usability of soft tools by adding a hardened layer of material to the tool surface.
- Tooling lead time reduction (approximately 5 weeks turnaround time versus 10 weeks or more for small tools, made conventionally).
- Significant injection mold cycle time improvements due to improved cooling (however, this is not a low-volume production objective.)
- Production of laminated tooling is generally about 50% of conventional tooling (conventional tooling will have a longer life for higher volumes, but this is not needed for low-volume production).

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J. Flexible Assembly

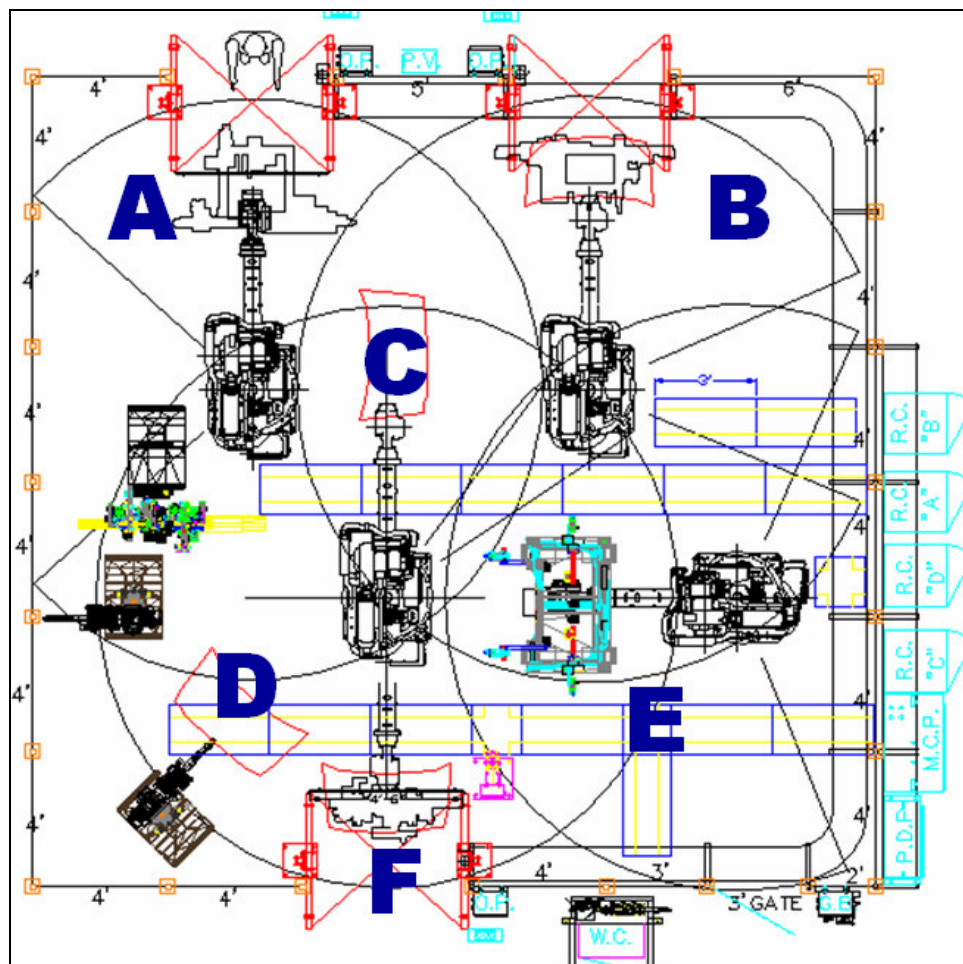
Description

Cosma (a division of Magna International) has developed a flexible, fixtureless assembly process for sheet metal parts. The cell would be competitive for high-volume or multiple small-volume vehicle production. The "Flex Cell Architecture" uses highly automated and controlled robotic cells. The three components of the cell are: 1) Modular End Effector Tooling, 2) Collaborative Robots, and 3) Controls Integrated with Human Interface. A key

1. Modular End Effector (see figures below)
 - Lightweight and modular for quick load/unload
 - Laser tracking for accurate geometric locating
 - Functions include locating, welding, sealing and geometric dimensioning
2. Collaborative Robots
 - Multiple robotic axes controlled with a single controller
 - Improved synchronization
 - Multi-purposes (handling, sealing, spot welding, arc welding, fixture-less systems)
3. Controls Integrated With Human Interface
 - Category IV safety with human interface
 - Controls allow individual or work groups of robots, turntable, servo-gun, etc.
 - Networking and real-time data collection

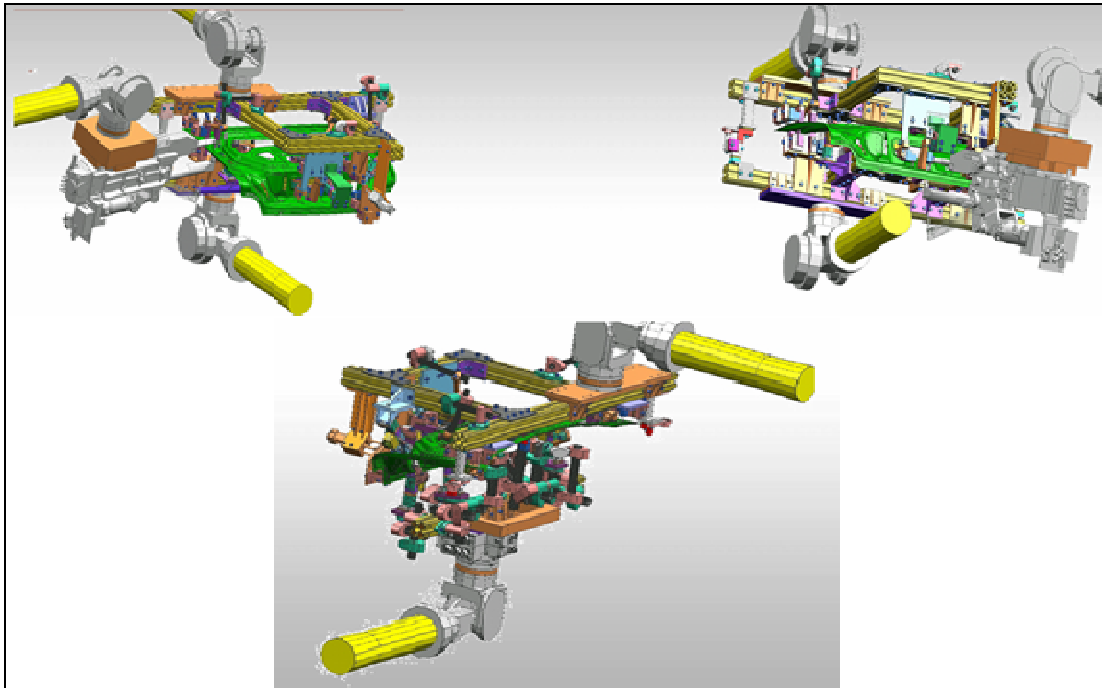
The Flex Cell approach is applicable for many body-in-white assemblies including doors and closures, underbody, and body side assembly. Additional technologies that can be integrated with it are MIG welding and remote laser welding.

Figure 46 – Flexible Collaborative Tool Cell



- A – Load loose details
- B – Load deck lid inner panel
- C – Marriage and geometry weld
- D – Pedestal weld
- E – Roll hemming
- F – Part exit

Figure 47 – Robotic Welding, Collaborative Actions (Mating Parts), and Robotic Handoff Movements



Business Case

Although the Cosma flexible assembly process is clearly unique, it offers many performance capabilities similar to the Honda flexible body shop that employs high accuracy robots in place of many geometry fixtures. The benefits include:

- Increased launch/start-up times because of modular design and carry-over equipment across sub-assemblies (approximately 25%).
- Reduced floor space with less material handling equipment, less work-in-process, and less bulky tooling stations.
- Lower investment costs (depending on the components, but 20% to 50% lower for closures)
- Manpower reduction from 20% to 50%.
- Nearly the same cycle time as dedicated production systems with some degradation possible due to robotic changeover (end effecters). Robotic linear speed is also reduced by 25% when collaborative motion is used.

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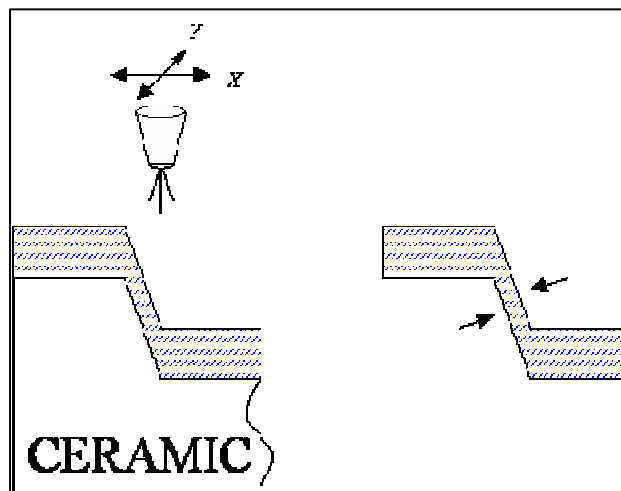
K. Spray Metal

Description

Ford Research Laboratories has developed a low-cost tooling process involving spray metal (<http://www.fordbetterideas.com/tc/main/featuredtech/rapidtool.htm>). Spray metal is an additive process (spraying metal onto a substrate), rather than one that removes metal, such as by machining. The Ford process uses an epoxy backfill that is removed once the metal has been sprayed onto the form. Once the backfill is removed, some structure has to be added to give the tool strength and rigidity. Ford's goal has been to find commercial development partners. Several Michigan tooling companies have partnered (through a licensing arrangement with Ford) to help develop the technology. While the technology has been used on some simple parts in automotive, there have been some challenges that have brought the process' viability into question. The most difficult challenge has been that the sprayed metal shrinks so that the net tool shape is difficult to anticipate. The extent to which this prohibits further development of the process is not certain. Tools that have been developed with this process include:

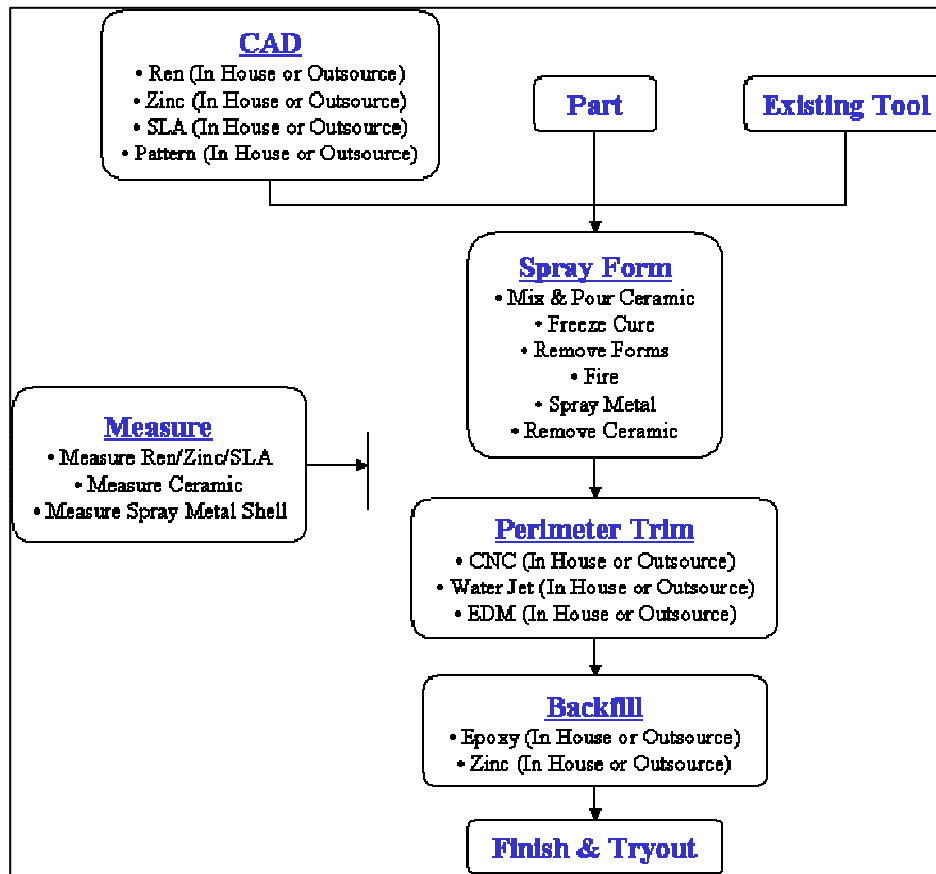
- Stamping tools
- Injection-molding tools
- Blow-molding tools
- Casting and die casting tools
- Thermoforming tools

Figure 48 – Spray Forming Process



Spray booth operates with one robot that has two degrees of freedom (X-Y planar movement). Four spray heads dispense metal to the casting. Parts are limited to shallow draws due to limitations in spraying (stress control and wall thickness).

Figure 49 – Spray Metal Construction Process



Business Case

The current process has been geared toward small tools (up to three feet by three feet). The cost advantage for tools in this category is that they are approximately 30% to 50% cheaper with the spray metal process. Larger tools can be constructed by combining two or more smaller tools; however, the cost advantage will diminish.

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L. Flexible Hemming (Roller Hemming)

Description

- Utica Products, Inc. has developed a flexible hemming system that is based on a roller hemming operation. Roller hemming is a process in which a robot's end-effector is equipped with a roll that bends a flange to create a hem. This is done by moving the roll at an angle along the flange, in several cycles.
- The first station in the company's flexible hemming system is an optional pre-work station in which the panels may be clinched or in which pre-hemming may be performed. A transfer robot moves the assembly from the pre-work station into a hemming fixture where two robots perform the roller hemming operation. The inside window header opening and beltline might also be flanged with cams, if required. Upon completion, the transfer robot loads the assembly onto a conveyor or exit station.
- Figure 50 shows a roller hemming cell for doors. In this example, there are four fixtures in the center of the cell which allow the processing or hemming of four different door models. The number of fixtures, which may be expanded to six or eight, is mainly limited by the available cycle time for the cell.
- Figure 51 shows a system for hoods and deck lids. The processing steps are the same as for doors. Doors, hoods and deck lids can also be made in the same cell.
- The system is not designed to include the application of glue/sealant or the curing of hemmed assemblies. Those operations typically take place outside this system.

Performance

- The advantage of the roller hemming system is its flexibility related to the cycle time and the number of different doors, hoods or deck lids that can be processed. The output of the system is about 90 jobs per hour in a system with 4 hemming stations. The output may be limited to 20 jobs per hour if 8 different products are to be made.
- It might be required to change the end-effector to hem different types of flanges. The Utica process has a quick change roller assembly that can be changed in about 10 seconds.
- The accuracy of the robots has limited influence on quality, as the head compensates for positioning errors with its floating hydraulic piston. This means that any type of robot manufacturer can be used.
- The above compensation mechanism also expands the model range for the system as it allows the hemming of closure panels that are designed as TWB's.
- The quality of the hem is comparable to the quality of those done with a conventional press type or table-top hemmer.
- There is about 35-55% less floor space required compared to conventional hemming systems. The company's system also requires less space relative to other roller hemming systems. One reason is the vertical alignment of panels in the hemming fixtures which minimizes the number of robots and,

thus, floor space. The easel fixtures also facilitate ergonomically friendly access for the robots and for maintenance.

Business Case

- The system may be scaled for speed or for flexibility as described above. The cost largely depends on the number of models for each system. The following table summarizes this cost for up to four models:

Table 5 – Typical Budgetary Cost System

Cost Comparison	Doors		Hood/Deck lid	
	System Cost	Total Cost	System Cost	Total Cost
Base System	\$850,150	\$850,150	\$791,400	\$791,400
Robots (Budget Cost)	\$140,000	\$990,150	\$105,000	\$896,400
2nd Model	\$414,250	\$1,404,400	\$439,200	\$1,335,600
3rd Model	\$361,500	\$1,765,900	\$332,000	\$1,667,600
4th Model	\$361,500	\$2,127,400	\$332,000	\$1,999,600

- In contrast to traditional hemming systems, a large majority of the roller hemming system components can be reused in a new vehicle program. Components that need to be replaced are mainly the holding fixtures and the robot end-effectors.

State of Readiness

- The Utica system is in operation in one North American high-volume assembly plant.

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Figure 50 – Door Roller Hemming System

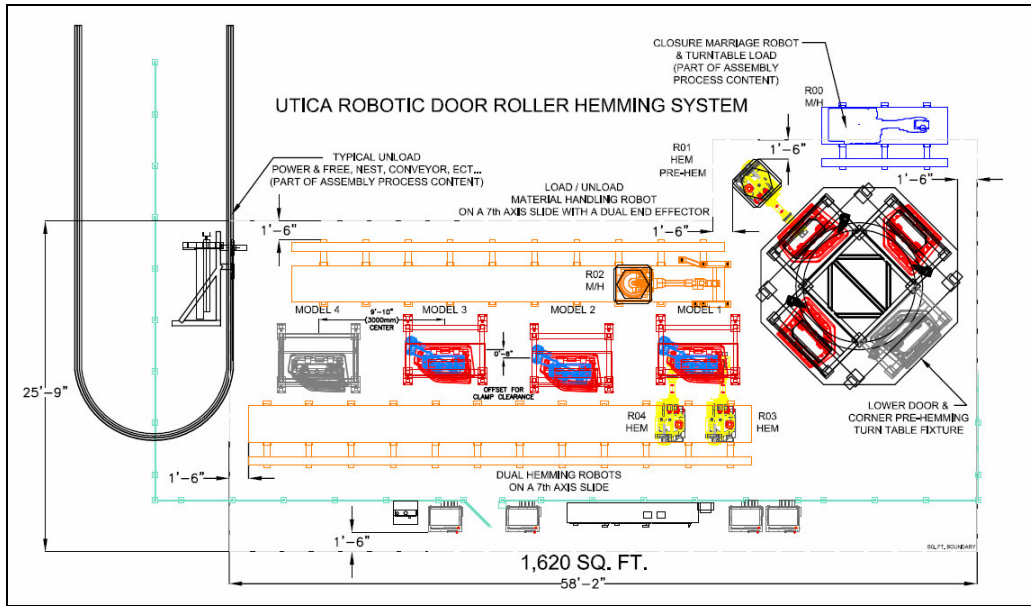
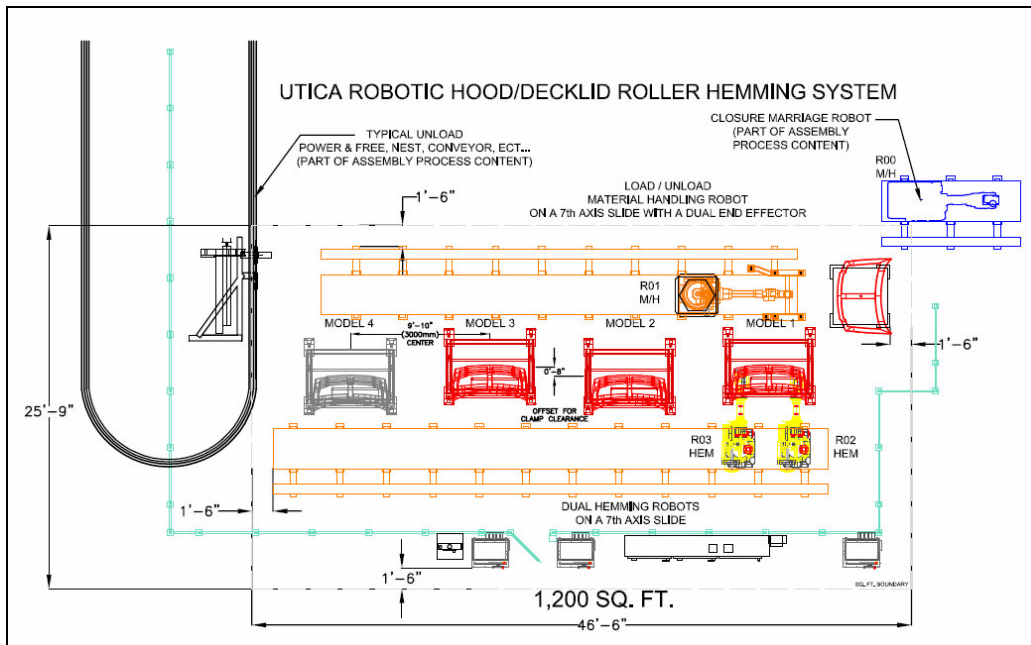


Figure 51 – Hood/Deck Lid Roller Hemming System



M. Tandem Mold

Description

- Tandem molds are used to make up to two parts in two cavities using a specially designed mold. The main goal of this technology is to increase the output of the molding operation. The technology is suitable for parts with any thickness and especially for family parts (e.g., right and left part). If cooling time is longer than 40 % of the total cycle time, the machine output can be doubled.
- The tool consists of two sets of cavities in stacked parting lines that can be used independently of each other.
- Tandem molds do not require special machinery and they can be used on standard horizontal presses.
- T/Mould GmbH & Co KG in Germany holds worldwide patents on this technology; they work with the Bielefeld University in Germany on its development.

Performance

- It is estimated that 20-30% of all automotive plastics parts may be produced more efficiently using this technology.
- Any size of automotive parts can be made using this technology. The largest tools in production currently run on 1800 ton presses.
- The technology was originally designed for parts with low-volumes and large cycle times. Recent tests have shown that the technology is also viable for high-volume applications.
- The quality of parts is comparable to those of standard molds.

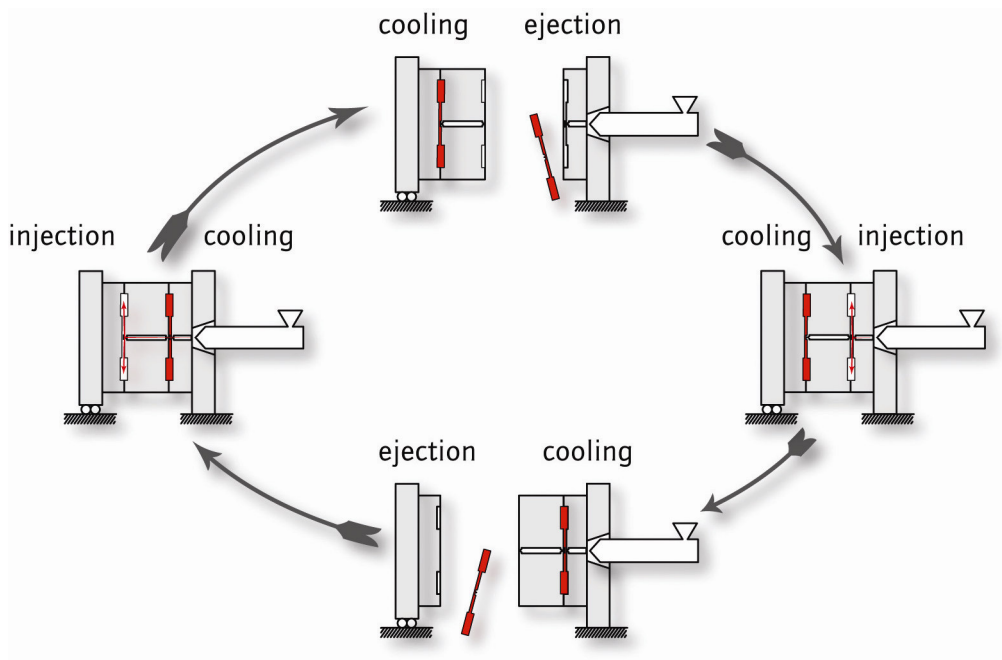
Business Case

- A tandem mold is generally not more expensive than two standard molds because the mold cost is roughly proportional to the number of cavities. The cost of the locking mechanism required for the alternating operation of the additional parting line is smaller than 10 % of the mold price. The melt passage system is designed similar to that type of stack molds.
- Despite the higher investment cost, a production cost savings of 40 % can be achieved if the cooling time accounts for 50% or more of the total cycle time. The cost savings is due to the higher efficiency of the molding machine that can run two molds at the same time.

State of Readiness

- There are currently 200 tools used in the production of parts.
- Future research includes:
 - utilization of TandemMould with thermo set material
 - standardization of the interface between two parts of TandemMould to design TandemMould-modules for production of parts with similar material but different production volume

Figure 52 – Molding Cycle



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N. Multi-Spindle Machining Center

Description

- The multi-spindle machining center is a very specialized system that allows for efficient machining for a variety of parts (e.g., parts for chassis, transmissions housings, common rails, pumps, fittings, hydraulics and electric motors).
- The machining center has at least four independently controlled spindles that may be used for drilling, milling, threading, phasing or turning. The machine also includes a 5-axis work piece holder that can carry up to 16 parts of one family type or up to 4 different families. Other major components include:
 - Automatic tool changer with magazine
 - Tool monitoring equipment
 - Quality control system with compensation capabilities
 - Automatic loading and unloading system
 - Conveyor belt for part transfer
- A picture of the machining center is shown in Figure 53.
- The work piece holder may be configured to run different parts at the same time. It is also designed to minimize idle when replacing parts in the working area.
- Due to the machining center's flexibility and the limited resources needed for production, the multi-spindle machining center is ideal for high- and low-volume machining runs.

Performance

- The machine is used in automotive for runs of 1,000 to 300,000 parts.
- The changeover time from one job to another is about 30 minutes.
- The idle time between the machining of different parts is less than two seconds.
- The tool wear is monitored and recorded automatically.
- Machined parts may be checked for quality automatically. Any deviation from nominal is automatically compensated for in the subsequent run.

Business Case

- The center is designed to be used by a single operator. It replaces capital-intensive and dedicated transfer lines. In one example, a Porsche supplier used to make a knuckle for a suspension assembly in a transfer line consisting of several stations and multiple fixtures. The cycle time in this process was about 17 minutes. This production line was replaced by a single machining center, in which the part is machined in a single fixture in four minutes. The machining center is also used by this supplier to make additional parts.
- For any new program, the cost to modify the machining center is about 10% of the initial investment cost. This modification mainly includes the replacement of fixtures and tools. In addition, new software needs to be uploaded to the machine.

State of Readiness

- The multi-spindle machining center is currently used at various plants in Europe and at a few plants in the United States. It is used for high- and low-volume runs.
- The current product spectrum could be expanded to other parts, such as engine or transmission parts.

Figure 53 – Multi-Spindle Machining Center

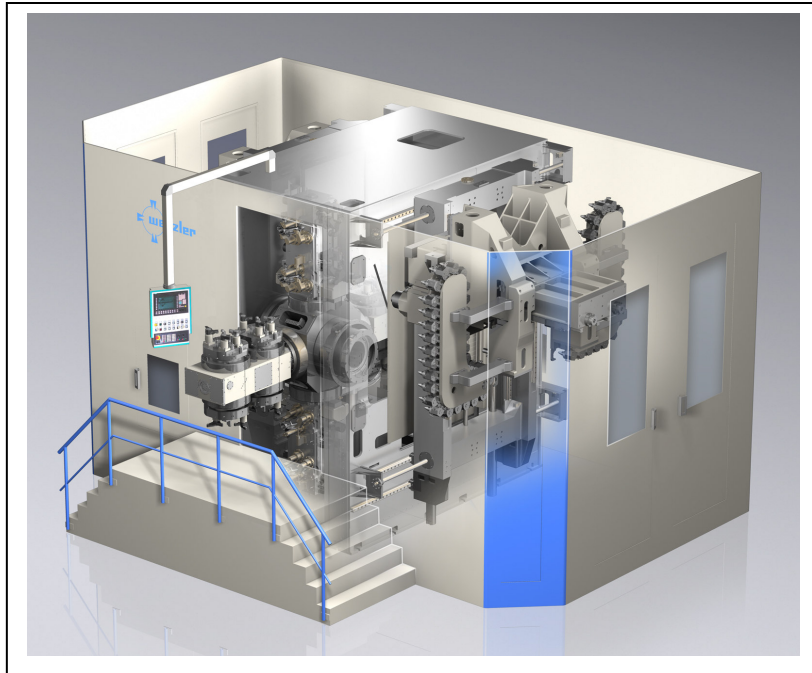


Figure 54 – Subset of parts that are machined on the multi-spindle machining center.



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Appendix 2

European Vehicle Integrators

The European automotive industry has developed a legacy of vehicle integrators. While the model may—or may not—be directly applicable to the North American market, it is important to draw attention to those companies that have vehicle integration capability. This appendix briefly describes the major European vehicle integrators.

Heuliez:

Heuliez is a French company that provides niche vehicle manufacturing, including product development, manufacturing, modules, and retractable hard top systems. Heuliez currently employs approximately 1,600 people.

The company's only manufacturing facility is located in Cerizay, France and has a capacity of 90,000 vehicles per year. Engineering and product development takes place at a facility in Le Pin, France. Heuliez also operates a showroom/design center in Paris. Currently, Heuliez produces two models for Peugeot Citroën: the CITROEN Saxo "Electrique" and the Peugeot 106 "Electric." The company's roof system is currently used on the Peugeot 206 Coupe Convertible.

Karmann:

Karmann is a privately held company that supplies the automobile industry with various components (including roof designs) as well as final production services. The company is based in Osnabruk, Germany and employs approximately 10,000 people. Karmann is broken down into four main divisions: vehicle engineering, tooling, roof systems, and production (vehicle assembly).

Final production, as well as most component and engineering work, occurs in various German facilities. Karmann also operates several plants and engineering facilities around the world. In the United States, Karmann produces the roof system for the Pontiac G6 and operates an engineering center. A Mexican plant produces roof systems for the Volkswagen Beetle; a Portuguese plant makes interior parts; and a Brazilian plant offers tooling, stamping, and vehicle production.

Current production models are the Chrysler Crossfire coup and convertible and the Mercedes CLK convertible. Roof systems appear on the Volkswagen Beetle, Renault Megane, Nissan Micra, and the Pontiac G6. Future production includes a Bentley model and the Chrysler Sebring roof system.

Magna Steyr:

Magna Steyr is a wholly owned subsidiary of Magna International that sells total vehicle engineering and concept development. The company is headquartered in Oberwaltzdorf, Austria and employs approximately 10,000 people. Magna Steyr is separated into three divisions: engineering, vehicle assembly, and space technology. The engineering division provides vehicle development services, system integration services, and prototype/low-volume production services to automotive manufacturers. The vehicle assembly division produces niche vehicles as well as derivatives of high-

volume vehicles. Finally, the space technology division provides manufacturing and technology services for aircraft, satellites, and automotive manufacturing.

Magna Steyr assembles all vehicles in its Graz, Austria facility. The company also runs engineering facilities in Austria, Germany, France, India, and the United States. Modules and components come from various plants in Austria and Germany.

The current production at Magna Steyr consists of eight different nameplates from a variety of OEMs: the Mercedes E-Class 4matic and G-Class, Jeep Grand Cherokee and Commander, Chrysler Voyager and 300C (sedan and wagon), Saab 9-3 convertible, and the BMW X3.

Pininfarina:

Pininfarina is a publicly traded company on the Borsa Italiana securities market that provides manufacturing, engineering, and prototype services to various car manufacturers. Based in Turin, Italy Pininfarina employs approximately 2,600 people and is separated into two divisions: manufacturing and services. Manufacturing provides dedicated niche vehicle production services to a variety of automotive partners. The services division consists of design and engineering which encompasses all services from concept drawing to full prototyping.

Pininfarina operates facilities in Italy, France, Germany, Sweden and Morocco. Three manufacturing plants are located in Turin: Grugliasco, San Giorgio, and Bario. The company also operates two plants in Uddevalla, Sweden to support Volvo activities and produce retractable hard top roof systems. Engineering and prototyping services are located in various Italian locations, Morocco, France, and Germany.

The current product mix at Pininfarina consists of the Alpha Romeo Bera, Volvo C70, Ford Streetka, and Mitsubishi Pajero Pinin. Products announced for 2006 include: the Alfa Romeo Spider, the Mitsubishi Colt C.C. and the Ford Focus C.C.

Valmet Automotive:

Valmet is a part of the Metso Corporation that provides engineering and design services, as well as niche vehicle production to assist OEMs with low-volume operations. The company is located in Uusikaupunki, Finland and employs approximately 800 people.

Valmet's facility in Finland is capable of producing approximately 100,000 vehicles per year and also includes a body shop, paint shop, and technical center. The company currently produces the Boxster, Boxster S, and the Cayman S. Valmet also produced several of the previous generation Saab 9-3 variants.