Offshoring Automotive Engineering:
Globalization and Footprint Strategy in the Motor Vehicle Industry

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Table of Contents

Executive Summary 4

The Shifting Nature of Engineering in the Automotive Industry 7
The Nature of Engineering Work in the Automotive Industry 7
The Key Driver of Change: Increasing Engineering Efficiency 10
Evolving Knowledge Boundaries between Vehicle Manufacturers and Suppliers 11
Toward a More Open Innovation Process in the Automotive Industry 12
Changes in Automotive Engineering from the Perspective of Engineers 13
Skills and Credentials Required for Entry-Level Engineers in the US. 14
Production of Qualified Engineers in Various Countries 14

Globalization of the Automotive Industry 15
Historical Context of Globalization in the Automotive Industry 15
Current Degree of Globalization in the Industry: Production, Employment and Sales 17
Globalization of the US Automotive Market 19
Globalization of the Automotive Supplier Industry 22

US Engineering Workforce in the Automotive Industry 25
Overall Employment in the US Auto Industry 25
Engineering Employment in the US Automotive Industry 26
Engineering Wages in the US Automotive Industry 27

Dynamics of the Automotive Engineering Global Footprint 29
Definition of Offshoring 29
The Dynamics of Automotive Engineering Footprint Management 29
The Value of Proximity 30
3C-G Customer Factor: Assessing Market Growth Opportunities 33
3C-G Cost Factor: Assessing Labor Rates and Total System Costs 36
3C-G Capability Factor: Assessing Regional Skills 40
Globalization of Automotive Engineering: Improving Coordination of Global R&D 43
Globalization of Automotive R&D: Domestic Firms Increasing Foreign R&D Employment 46
Globalization of Automotive Engineering: Foreign Firms *Onshoring* R&D 47
Discussion: Are Automotive Engineering Jobs Being Offshored? 48

The Growth of Automotive Engineering in China 50
The Rise of the Chinese Auto Industry 50
Impact of China on US Vehicle Manufacturers and Suppliers 51
Chinese R&D Capability 52

Looking Forward: Trends and Projections 55

References 56

Table of Figures

Figure 1 Top Industries by 2006 Estimated R&D Spending 7
Figure 2 Top 20 Global Companies by 2004 R&D Spending 7
Figure 3 Product Architecture Map of the Cars, Heavy Trucks and Some Other Common Products 9
Figure 4: Market Capitalization of Automotive Firms by Region: 1973-2005 10
Figure 5: Adjusted Product Engineering Hours for Vehicle Manufacturers in Three Regions 11

Figure 6 CAE Tools Have Changed the Engineer's Work Environment ... 13
Figure 7 Engineering, IT and CS degrees awarded in 2004 in USA, India and China ... 14
Figure 8 Offshore CKD Assembly Plants of Ford, GM and Chrysler up to 1928 ... 15
Figure 9 Percent of Employees, Sales and Production Outside Home Country for Top 10 Global Automakers ... 17
Figure 10 US Vehicle Sales by Category ... 18
Figure 11 Foreign-Brand Market Share in the United States: 1986-2005 ... 19
Figure 12 US Sales of Foreign-Brand Vehicles Split by Transplant-Produced and Imports ... 20
Figure 13: Transplants in the United States ... 20
Figure 14 US Light Vehicle Production (Domestic and Transplant): 1982-2005 ... 21
Figure 15: Some Non-US Suppliers to the 2005 Dodge Dakota ... 24
Figure 16 Japanese Automaker Purchases of US Parts: 1986-2005 ... 24
Figure 17 US Automotive Industry Employment 1990-2006 ... 25
Figure 18 Annual Mean Wages for Engineering Occupations in the US Automotive Industry ... 28
Figure 19 Framework for Defining Offshoring and Outsourcing ... 29
Figure 20: 3C+G Global Footprint Model for the Automotive Industry ... 30
Figure 21 Impact of 3C-G Factors on Manufacturing Engineering versus Product Engineering Footprint 30
Figure 22 Proximity Value for Automotive Production and Product Engineering ... 32
Figure 23 US Light Vehicle Sales 1982-2005 ... 34
Figure 24 Vehicles Sales Growth Rates in Key Markets ... 34
Figure 25 Vehicles Per 1000 People: Selected Countries / Regions ... 35
Figure 26 Vehicle Production by Country/Region Normalized to 2005 ... 36
Figure 27 Approximate Fully-Loaded Annual Automotive Engineering Labor Rates by Country/Region for an Automotive Engineer with 5-10 Years Experience ... 40
Figure 28 Engineering Task Complexity and Difficulty of Outsourcing/Offshoring ... 41
Figure 29 Conceptual Model of Capability versus Transportability Trade-Off in Various Engineering Disciplines ... 43
Figure 30 Evolution from International and Multinational to the Transnational Model for Automakers ... 45
Figure 31: General Motors Global Engineering and Design Facilities ... 46
Figure 32 Foreign Brand R&D Centers in the United States ... 47
Figure 33 US Technical Employment at Japanese Automakers ... 48
Figure 34 Automotive-Related Patent Applications in China: 1985-2005 ... 54

Executive Summary

The global automotive industry is fiercely competitive. Both vehicle manufacturers and suppliers are under intense pressure to reduce costs, and engineering costs are an important component of the automotive cost structure. Ford Motor Company spent $8.0 billion on R&D in 2005 (4.5% of its $177 billion revenue), which is more than any other company in the world. Over 90% of that spending was for engineering and development (as opposed to basic research). Firms that can bring vehicles from concept to customer faster, better and cheaper have a powerful competitive advantage. Footprint strategy – determining where to deploy labor and capital on a global basis – is a key lever for increasing engineering efficiency.

The automotive industry has been international since its inception, and the globalization process continues despite some recent divestment (e.g., the GM-Fiat split). In 2005, General Motors became the last of the top ten global automakers to sell more vehicles outside its home market than within. (Volkswagen sold 80% of its vehicles outside of Germany.) Nearly one out of every three vehicles built in the United States in 2005 was built at one of the 17 foreign-brand *transplant* assembly plants. The industry has historically followed a "build where you sell" strategy. Ford and GM followed an "engineer where you sell" strategy as their European operations developed throughout the 20th century. Toyota and Honda have more recently shifted engineering work to outside Japan. The automotive supply base – a critical component of the industry – is also global. Today's vehicle manufacturers "shop at the global mall," that is, they source components regardless of the headquarters location of the supplier. Over 40% of the sales of the top North American suppliers were to customers outside North America.

An estimated 189,000 engineers are employed in the United States by the automotive industry, including both product and manufacturing engineers at both vehicle manufacturers and suppliers. Among vehicle manufacturers, engineering employment has been declining among the domestic vehicle manufacturers and increasing among foreign vehicle manufacturers. Honda, BMW, Hyundai and other foreign vehicle manufacturers employ an estimated 4,000 engineers in the United States. This figure has been growing rapidly (about 150/year over the past 7 years accelerating to about 500/year over the past year). Ford and GM are reducing their 23,500 engineers in the United States. This pattern is similar in production: Ford and GM are closing assembly plants in the United States while Toyota, Honda and Hyundai are expanding their US production footprint. Annual mean wages for mechanical and industrial engineers have been stable at roughly $66,000 (unloaded) through May 2005.

This report argues that there are four primary factors that automotive managers consider to make location decisions:

- Customer: Where is the vehicle market growing? In which segments?
- Cost: What are the local engineering labor rates? What are the internal transaction costs?
- Capability: Where are engineers with specific capabilities located?
- Government: What is the influence of government trade and investment policies?

The weighting of these factors is different for locating R&D (product engineers) versus locating production (manufacturing engineers, who usually are located with production facilities).

One of the key findings is that the automotive world is not flat; there is value to proximity in the automotive industry. Product engineers that "localize" a vehicle to comply with local customer and regulatory requirements are best located in the destination country. Product engineers that work on vehicles that dominate a given regional market (e.g., pickup trucks in the United States) are also best located in that regional market. The integral architecture of the automobile – the fact there is little one-to-one correspondence between functional and structural elements – frequently requires that supplier engineers work very closely with their counterparts at vehicle manufacturers. There are also many reasons when supplier production facilities (and therefore supplier manufacturing engineers) should be located close to the vehicle assembly plant: parts that are difficult or costly to transport or parts that need to be carefully sequenced with the assembly plant build order are examples.

Vehicle sales have been flat in the key developed markets of the United States, Japan and Western Europe over the past five years. In dramatic contrast, vehicle sales in China, India and Russia have exploded. (China is now the second largest automotive market in the world, after the United States, on a volume basis.) Vehicle manufacturers have followed the market growth in these key countries by investing in production facilities. Suppliers have followed their OEM customers.

Cost has been a key factor in location decisions. Mexico and, to a lesser degree, Canada have been low cost production centers for US-destined vehicles for years. Similar low cost production centers have emerged for Western Europe (Czech Republic, Poland, Slovakia, Slovenia and Hungary) and for Japan (Thailand, Malaysia, Indonesia, Philippines). To some degree, engineering has also shifted to these locations; however, China and India remain key low cost markets of interest in engineering because of the high growth in their home markets. Engineering labor rates can vary as dramatically as production labor rates. Automotive engineers in China can easily cost the employer one tenth of an engineer in the United States or Germany. Some automotive components – particularly labor intensive, less technologically sophisticated components – make sense to offshore production to a low cost country. Other automotive components – particularly capital and technology intensive products – make less sense to offshore to a low cost country. Interviews revealed that suppliers frequently underestimate the cost to ramp up production in a low cost country.

Capability is another key factor in footprint strategy. Certain engineering tasks and functions are easier to offshore than others. Repetitive or routine tasks that require moderate technical skills are easier to offshore, such as generating a finite element mesh, certain routine heat transfer or stress analysis calculations, or documenting an engineering bill of materials. Technically sophisticated tasks are more difficult to offshore. The process of engineering vehicles involves a web of transactional relationships among engineers from the vehicle manufacturer and many suppliers. There are frequently multiple iterations among these engineers because, for example, a change in the dimension of one part may create a heat transfer problem with another part. Offshoring design of integral components – versus offshoring simple engineering tasks – can be highly disruptive to the vehicle development process. Interviews revealed that a lack of automotive domain knowledge has hampered efforts to develop engineering resources in low cost countries.

Most vehicle manufactures are striving to better coordinate their existing global engineering resources rather than offshore engineers from high cost centers to low cost centers. Ford and GM are striving to share more parts among their global vehicle families while keeping products highly differentiated to the end customer. For example, automakers are trying to reduce the number of seat rail systems, the number of parts used in a horn, and the number of midsize V6 engines used among their global product portfolio. This is part of GM and Ford’s broader efforts to evolve from distributed and independent regional R&D centers to distributed but coordinated regional R&D centers. Toyota and Honda are striving toward the same goal, but from the starting point of a highly centralize R&D model.

Many interviewees expressed that offshoring – as defined by replacement of engineers in high cost countries with those in low cost countries – is the wrong way to frame the issue. Offshoring is one component of the broader issue of footprint strategy. Domestic companies can increase engineering headcount oversees (due to market growth and other drivers) while decreasing engineering headcount in the US without replacement of jobs as the underlying driver. Similarly, domestic companies can increase offshore engineering employment while foreign companies onshore engineering employment, as we have witnessed in the US automotive industry. Most interviewees felt that the debate over engineering offshoring is overblown and misunderstand.

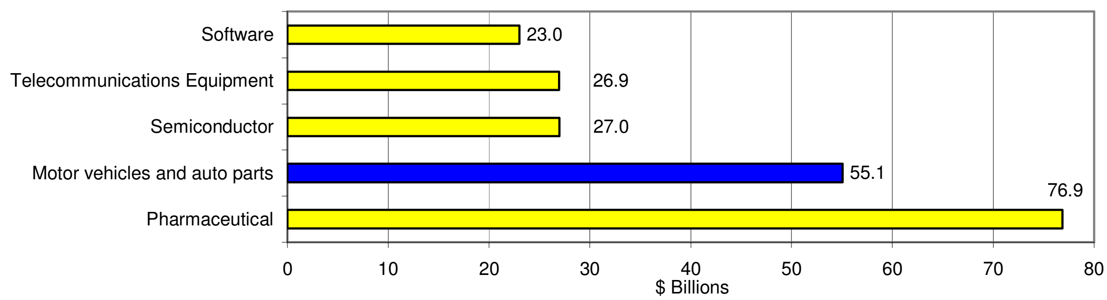
The most successful and valuable car company in the world, Toyota, has the lowest percentage of employees outside its home market (38%) of any of the top ten automakers. The company that has "offshored" the least remains the industry benchmark.

The Shifting Nature of Engineering in the Automotive Industry

The Nature of Engineering Work in the Automotive Industry

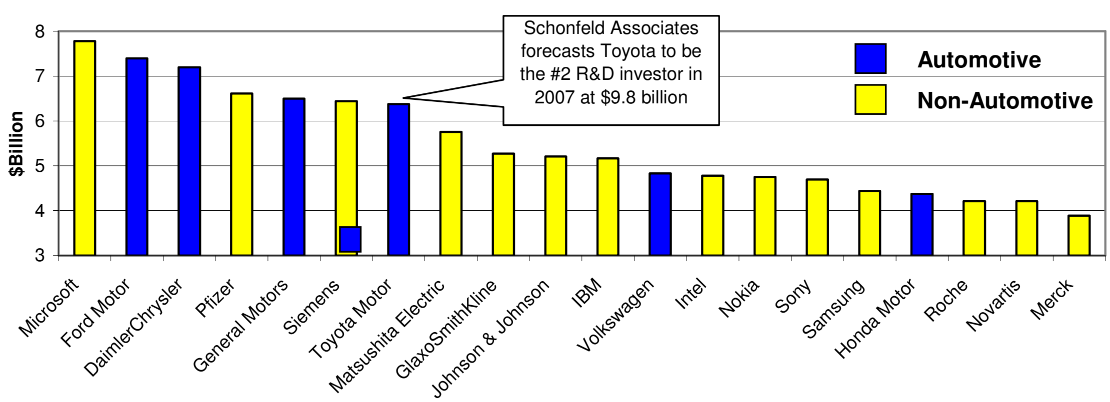
Engineering has always played a critical role in the global automotive industry. The global automotive industry spends more on research and development (R&D) than any other industry except the pharmaceutical industry, as shown in Figure 1.[1] Four out of the top ten global firms ranked by R&D spending are automotive companies, as shown in Figure 2. The vast majority of the global automotive industry's $55 billion R&D spending is on the D: development greatly outweighs spending on basic and applied research.[2] Most of the vehicle development process is performed by engineers and technicians. A typical new vehicle program costs between $500 million and $1 billion and requires two to three years from concept to customer. A new engine program costs roughly $100 million to $500 million, and a new transmission program costs roughly $50 million to $250 million. Corporate engineering capability is a key competitive differentiator for vehicle manufacturers.

Figure 1 Top Industries by 2006 Estimated R&D Spending



Source: *R&D Ratios & Budgets*, Schonfeld & Associates, June 2006
Note: Industry SIC Codes are: Software: 7372; Telecom Equipment: 3663 & 4812; Semiconductor: 3674; Automotive: 3711 & 3714; Pharmaceutical: 2834.

Figure 2 Top 20 Global Companies by 2004 R&D Spending



Source: *Corporate R&D Scorecard*, Technology Review; Industrial Research Institute; Company Annual Reports
Note: Siemens includes Siemens VDO automotive business, which accounted for 12.7% of 2005 revenue.

[1] If all information and telecommunications technology industries are lumped together, then automotive ranks as the third highest industry for R&D spending.
[2] Only some automakers could estimate the precise split, but for each of the three automakers who provided data, less than 10% of their total R&D spend was for research; more than 90% was for development.

There are two basic types of automotive engineers: product engineers and manufacturing engineers. Product engineers design cars and trucks and their components. They may focus on specific systems, such as braking, steering, or interiors, or specific components within those systems, such as ABS controllers, steering columns, or instrument clusters. Product engineers can be development engineers that evaluate prototype vehicles and tune the vehicle in the pre-production phase, for example, through calibrating the powertrain to meet the customer profile for the vehicle. Product engineers can also be test engineers that are responsibility for durability, stress, thermal, or noise & vibration testing. Although product engineering has traditionally been grounded in the mechanical and industrial engineering disciplines, the industry has increasingly hired electrical, electronics and software engineers due to the increased electronics and software content of vehicles. Many vehicle manufacturers operate advanced engineering departments that search for new ideas and develop new technologies for future vehicles.

Manufacturing engineers are responsible for determining the most efficient manner to produce the product. Some manufacturing engineers are employed as part of a central engineering staff dedicated to production; however, most manufacturing engineers are located in offices at the production facility, such as a vehicle assembly plant or a component manufacturing plant. Firms generally encourage close coordination between product and manufacturing engineers. Engineering approaches such as *design for assembly*, *design for manufacture*, and *value engineering* encourage product and manufacturing engineers to work together as a team to engineer excess cost or waste out of the vehicle. Manufacturing engineers tend to be trained in the industrial and mechanical engineering disciplines.

The importance of the automotive supply base within the automotive industry cannot be understated. A typical automobile is made of 20 to 30 thousand individual parts engineered into hundreds of components and sub-systems. Vehicle manufacturers purchase between half and three quarters of these parts from their suppliers. All the major vehicle manufacturers spend at least 50% of their revenue to purchase components from suppliers.[3] Vehicle manufacturers increasingly specify overall system requirements where their suppliers are free to engineer and design a component or vehicle sub-system as they see fit to provide a solution for their customer. This is in contrast to the traditional business model of vehicle manufacturers giving their suppliers detailed technical specifications for components and asking their suppliers to manufacture those components, although this model still exists for many components.[4] Supplier engineers play a critical role in introducing technology into vehicles and frequently work closely with engineers at the vehicle manufacturers.

There are hundreds of firms that primarily supply the automotive industry, many of which have consolidated into global enterprises employing thousands of people in facilities spread across the planet. The industry supply base is tiered. A tier one supplier sells directly to the vehicle manufacturers (for example, BorgWarner may sell a transmission to General Motors), and tier two suppliers sell to tier one suppliers (for example, Timken may sell roller bearings to BorgWarner). In practice, the distinction between tier one, tier two and tier three suppliers is often blurred, where some very small firms may sell directly to vehicle manufacturers, but should not be considered tier one suppliers for analysis purposes. There are also firms that are not thought of primarily as automotive firms, but who have large automotive businesses, such

[3] However, there are sometimes significant equity relationships between vehicle manufacturers and suppliers, as in the case of the Japanese *keiretsu* system where, for example, Denso and Aisin Seiki, two large Japanese suppliers, are partially owned by Toyota. In France, PSA Peugeot Citroën and Faurecia have an equity relationship, as do Hyundai-Kia and Mobis in South Korea.
[4] See Fujimoto for more on the rise of the "black-box parts ratio" in automotive product development.

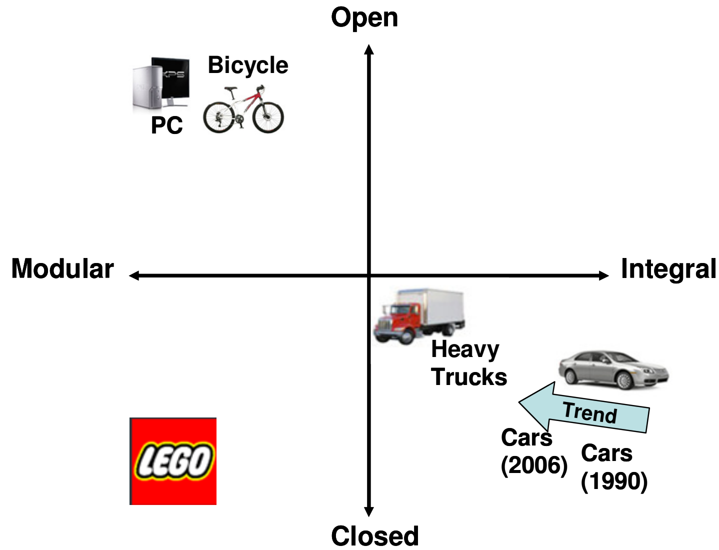
as Freescale (formed when Motorola spun off its automotive semiconductor business), Siemens, Sumitomo Electric, DuPont, and even Microsoft. We should also consider the many firms that supply production equipment to the automotive industry, such as stamping presses or robotics systems, and the firms that supply test equipment to the industry, such as dynamometers and road simulators. All of these automotive suppliers employ product and manufacturing engineers.

Product architecture is the relationship between the functions and the structures of a product. The product architecture of the automobile has a large influence on how automobiles are engineered. Following the work of Fujimoto, some basic terminology is helpful:

- Modular architecture: a one-to-one correspondence between functional and structural elements
- Integral architecture: a many-to-many correspondence between functional and structural elements
- Open architecture: a mix and match of component designs across firms
- Closed architecture: a mix and match of component designs only within one firm

Figure 3 illustrates how some typical products fall within a product architecture matrix using the above terminology. The children's toy Lego is the best illustration of a perfectly modular yet closed architecture. The PC system and the bicycle are examples of products with modular and open architectures. PC components, such as printers and displays and other devices, are interchangeable among many manufacturers and are mapped closely to specific features (printers are used for printing). The product architecture of the automobile is integral and closed. There are complex interactions among the thousands of parts in an automobile; for example, a slight vibration from a gear set at a certain speed could set a floor pan into resonance. Further, the many internal parts of a vehicle are not interchangeable among manufacturers, even though the same suppliers may make very similar parts for different vehicle manufacturers. Although cars have a highly integral product architecture, they have become more modular over the past few years as vehicle manufacturers strive to reduce costs through modularization. Heavy trucks are significantly more modular and open than cars (e.g., trucks are ordered with engines from different engine manufacturers). The integral architecture of the vehicle often forces close and coordinated interaction among teams of engineers from vehicle manufacturers and suppliers.

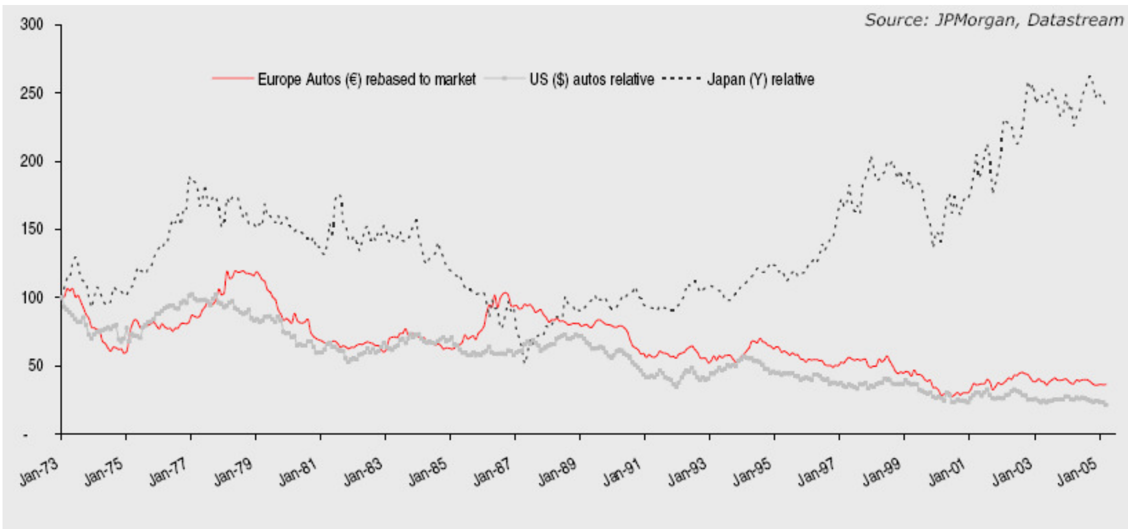
Figure 3 Product Architecture Map of the Cars, Heavy Trucks and Some Other Common Products



The Key Driver of Change: Increasing Engineering Efficiency

The majority of the world's vehicle manufacturers, and many of the tier one suppliers, destroy value from a financial perspective. In layman terms, these firms borrow money at a higher rate than the rate they earn on that borrowed money. Figure 4 shows that American and European automotive firms have lost value with respect to the overall market since 1973, while the Japanese automotive sector has returned value to investors.

Figure 4: Market Capitalization of Automotive Firms by Region: 1973-2005



Source: JPMorgan, Datastream
Note: Data normalized to January 1973. Each relative to overall regional market.

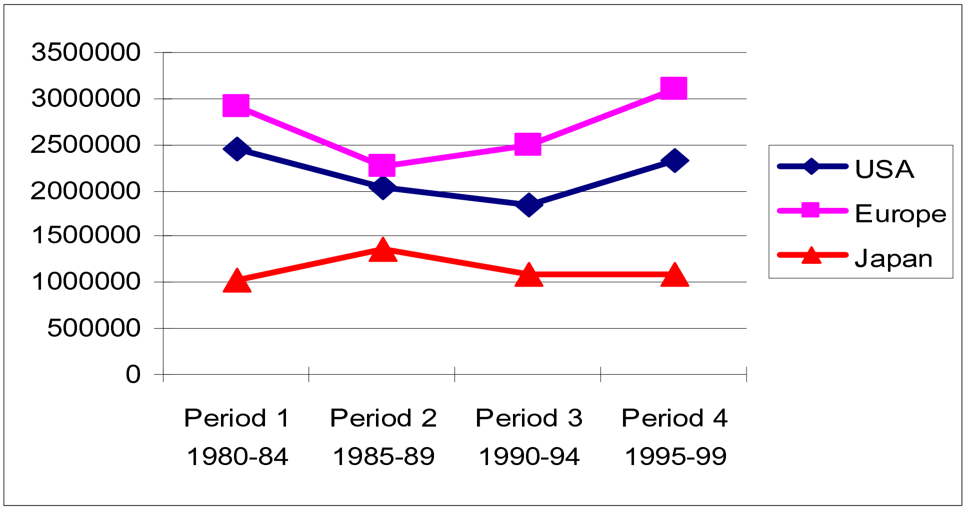
Some OEMs are profitable and create value – Toyota, Honda, Nissan, BMW and more recently Hyundai – but the rest have not for several years. For the most part, the fortunes of the winning camp and the losing camp are diverging. Toyota, the most valuable automotive firm by market capitalization, is currently valued at over ten times the value of General Motors.[5] Almost every manager and executive in the industry – even those within the profitable firms – reports a tremendous pressure to reduce costs while increasing performance. Today's global automotive industry is fiercely competitive.

In light of the extraordinary R&D costs for a typical vehicle manufacturer (as shown in Figure 2), firms that can engineer a vehicle at a lower cost and bring the vehicle to market faster will have an extraordinary advantage over their competitors. There are still significant differences among the world's vehicle manufacturers in their product development efficiency. Fujimoto, Clark, and Nobeoka have studied automotive product development for years. Their data demonstrate that engineering efficiency – as measured by engineering hours adjusted for a comparative vehicle program – is actually diverging among American, European and Japanese automakers. Figure 5 shows the product engineering hours required for a typical vehicle program averaged for vehicle manufacturers from three regions and shown over four time periods. (The data are presented as regional averages to mask the identity of the individual firms so, for example, an individual Japanese OEM may be less efficient than an individual American OEM.) Fujimoto notes that product engineering loads in the US and Europe have increased in the last five year period (between the early 1990's and late 1990's) due to the significant increase in regulatory

[5] Market capitalization as of October 15, 2006: Toyota $188.1 billion; General Motors $18.4 billion.

requirements. He argues that in Japan, the increase in regulatory requirements cancelled out the increase in engineering efficiency, to yield approximately the same number of engineering hours. Indeed, returning to Figure 2, it is entirely unclear whether vehicle manufacturers that spend more on R&D than their competitors have an advantage or disadvantage. One must also consider the efficiency of the firm's engineering operations to evaluate the actual R&D output.

Figure 5: Adjusted Product Engineering Hours for Vehicle Manufacturers in Three Regions



Source: Takahiro Fujimoto, University of Tokyo & Kentaro Nobeoka, Kobe University

One Vice President of Engineering of a vehicle manufacturer reported that his single greatest challenge is the pressure to do more with less. This manager is tasked with meeting a corporate target of increasing engineering efficiency by 30% over a three-year time frame – a remarkably ambitious objective. This particular manufacturer measures engineering efficiency by engineering output divided by total engineering costs. Engineering output is measured by a point system that assigns various weightings to the company's new vehicle programs, significant vehicle redesigns (known in the industry as product freshenings), and new powertrains.

This drive to increase efficiency – to increase engineering output while lowering engineering costs – is driving several interrelated developments in the industry. Most important among these are the following:

- Pressure to manage the global footprint more effectively across the enterprise
- Changes in the working relationship between vehicle manufacturers and their suppliers
- A shift toward a more open model of innovation to accelerate the innovation process.

Managing the global engineering footprint is the subject of this paper; the other two areas are addressed below.

Evolving Knowledge Boundaries between Vehicle Manufacturers and Suppliers

One of the most significant trends in the automotive industry over the past two decades has been the emergence of mega-suppliers capable of designing and developing large portions of the vehicle and, in some cases, manufacturing full vehicles. The largest tier one suppliers have been shifting their focus from components to full vehicle systems or "modules". Their customers, the vehicle manufacturers, have granted them greater engineering responsibility. Many vehicle manufacturers have announced plans to work better and closer with fewer suppliers.

Emergence of Contract Manufacturing in the Automotive Industry
The increasing importance of suppliers in the global automotive sector is symbolized by the emergence of contract manufacturers. Magna Steyr is a wholly-owned subsidiary of Magna International that builds full-vehicles for several OEMs. Magna International declared over $20 billion in automotive sales in 2005, ranking as the third largest automotive supplier in the world.[6] Magna Steyr's production volumes have grown steadily to 230,505 units in 2005 representing $4.1 billion in sales to OEM customers. The manufacturing complex in Graz, Austria, includes two assembly plants that build about 1000 vehicles a day, including the BMW X3, Mercedes E-class and G-class, Saab 9-3 convertible, Jeep Grand Cherokee, Chrysler 300 and Chrysler Voyager.

Magna has also moved into the upstream business of contract engineering for the automakers employing 2,300 engineers in ten locations around the world. The largest engineering center is in the Graz complex and employs 1,000 people. Magna Steyr says it completely engineered the 9-3 cabriolet, G class, BMW X3 and Audi TT coupe and roadster. It also performed engineering projects for Alfa Romeo, Audi, Iveco, Lancia, Lincoln, Pontiac, Smart and VW - from adding a body derivative to creating a four-wheel-drive version.

This blurring of the lines between OEMs and suppliers is reflected in DaimlerChrysler's Toledo Supplier Park in Toledo, Ohio. The 2007 Jeep Wrangler is manufactured at this facility with deep involvement of a variety of suppliers. Kuka Flexible Systems, a German company, runs the body shop. Magna-Steyr runs the paint shop. Mobis, a Korean company, supplies chassis modules. This is a marked contrast to traditional assembly plants, where the vehicle manufacturer is responsible for all of the above functions.

Toward a More Open Innovation Process in the Automotive Industry
Another result of the tremendous pressure to engineer vehicles more efficiently is a migration toward greater openness of the innovation process. Vehicle manufacturers have historically looked inward for new ideas and better ways to engineer vehicles. The previous section described how vehicle manufacturers are working closer with their suppliers. But beyond their suppliers, they are also turning to their competitors, universities, and even their customers to improve their products. Some examples include:

- Joint vehicle programs
- Technology alliances
- On-line technology brokers
- University research programs

Vehicle manufacturers have always shared vehicle programs among their internal brands. It was never unusual for a Buick and Oldsmobile product from General Motors to have different names but to be nearly identical products. We have also seen shared vehicle platforms among manufacturers with an equity relationship, such as Ford and Mazda. However, over the past ten years the industry has witnessed increased collaboration on vehicle programs among manufacturers that have no equity relationship and are otherwise fierce competitors in the marketplace. Some examples include the Toyota Aygo and the Peugeot 107, or the Pontiac Vibe and the Toyota Matrix.

Vehicle manufacturers that do not have equity relationships have also increasingly entered into technology alliances. The alliance that is currently of most interest in the industry is an

[6] Automotive News Global 100 Supplier List. 2005 revenue of top three automotive suppliers: Robert Bosch GmbH, $28.4 billion revenue; Denso Corporation, $22.9 billion; Magna International, $22.8 billion.

agreement announced in September 2005 among GM, DaimlerChrysler and BMW to develop a new hybrid electric powertrain to surpass Toyota's hybrid powertrain first developed for its Prius vehicle. GM and BMW have been collaborating on hydrogen refueling systems since May 2003, and Ford and PSA Peugeot Citroën have been collaborating on small diesel engines since March 2000.

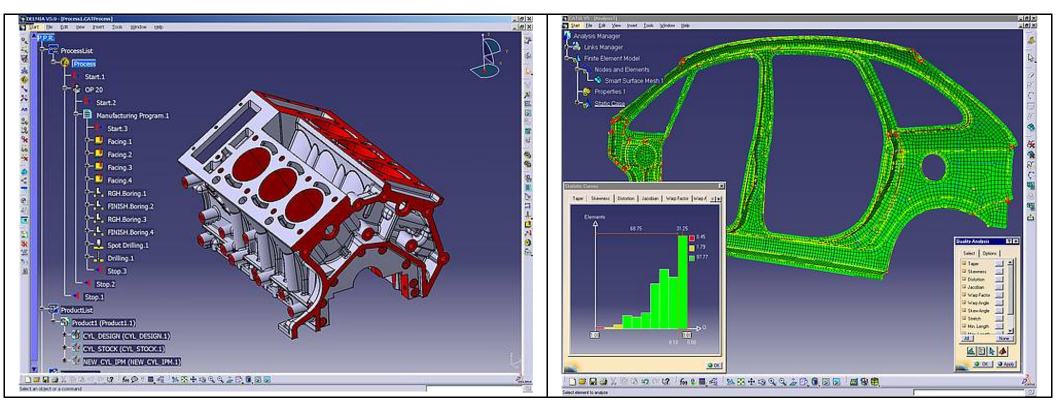
Vehicle manufacturers and suppliers have increasingly leveraged the internet to reach far outward for new ideas and technical solutions to specific problems. On-line technology brokers such as NINΣ, yet2com and innocentive are like an eBay for technology. Automakers and suppliers issue a detailed request for proposal (anonymously if they wish) that describes a problem for which they seek a solution. Researchers from all over the world can offer solutions at various stages of development, from a vague idea to a well-honed technology. BMW has taken the search for outside solutions directly to their own website, where anyone can offer a solution to what they view as a problem or need with a BMW product.

Automakers have reached out to universities for decades, but both the volume and depth of research funding seem to be increasing. GM established its collaborative research lab (CRL) program in 2002. The CRL program has established ten, long-term strategic relationships with professors or teams of professors at specific universities to focus on specific technical areas. The electronics and controls CRL with Carnegie Mellon University is one of the largest; others include engine technology at the University of Aachen and lightweight materials at the Indian Institute of Science. Ford and MIT have engaged in a multiyear, multimillion dollar research relationship as well. Toyota has pledged as much as $50 million to Stanford University's Global Climate and Energy Program.

Changes in Automotive Engineering from the Perspective of Engineers

At the working level, most automotive engineers interviewed report that the single greatest change they have witnessed since 1990 is the emergence of remarkable new tools that have changed their daily work routines. Most of these tools have been enabled by the tremendous advances in information and communications technologies that have occurred since 1990. In 1990, Computer Aided Design (CAD) and Computer Aided Engineering (CAE) were specialty areas where a small minority of engineers learned to understand the software. Now, design engineers have far more exposure to these increasingly powerful systems. For example, every Ford product engineer either has a dedicated UNIX workstation at her desk or shares a UNIX machine with a neighbor engineer. CAD systems enable an engineer to fit components together in a virtual 3-dimensional space, as shown in Figure 6.

Figure 6 CAE Tools Have Changed the Engineer's Work Environment



Source: Dassault Systemes

Access to information has greatly improved. From the company intranet, engineers can access assembly plant quality data in real time, call up engineering prints, engineering specifications and engineering test procedures. They can also assess critical data from their suppliers. The shifting knowledge boundary between OEMs and suppliers has had a clear impact on engineers on both sides.

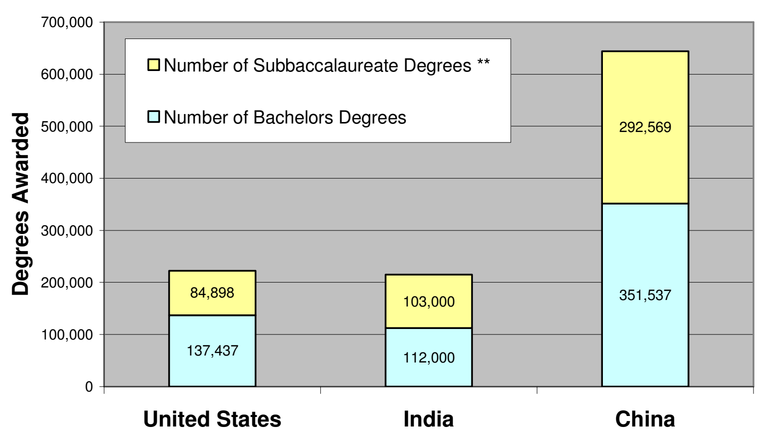
The role of engineers at vehicle manufacturers and suppliers has evolved with the shifting industry structure. When Ford spun off many of its automotive parts business to form Visteon, previous engineering work done in-house (such as axle engineering) was moved to Visteon. The same phenomenon occurred when GM spun off Delphi. Several OEM engineers described their role as shifting from a designer of components and sub-systems to a systems integrator. Several supplier engineers noted that their customers now give them greater autonomy to design components (or even full vehicle systems) – although the degree of autonomy granted varies by vehicle manufacturer.

Finally, some engineers stated that they are much more aware of potential legal liabilities related to their daily work than they were ten years ago. This especially affects how they document information. Many engineers also mentioned that, in general, it seems like there are less engineers doing more than 15 years ago. They feel the pressure to be more efficient.

Skills and Credentials Required for Entry-Level Engineers in the US.
A bachelor's degree in engineering or physics is the general requirement for entry-level engineer hires in the United States. Some interviewees noted that an increasing proportion of entry-level hires have master's degrees.

Production of Qualified Engineers in Various Countries
Several press reports have suggested that United States is loosing its technological lead by graduating fewer engineers relative to countries like India and China. Typical reports state that in 2004 the US graduated roughly 70,000 undergraduate engineers, while China graduated 600,000 and India 350,000. Duke University researchers determined that the data were not comparable. The numbers for China and India include three-year training programs and diploma holders, versus graduates from four-year accredited engineering programs in the United States.

Figure 7 Engineering, IT and CS degrees awarded in 2004 in USA, India and China



Source: Gereffi, Gary and Vivek Wadhwa, December 2005. *Framing the Engineering Outsourcing Debate*, Duke University.
Note: Subbaccalaureate degrees refer to Associates degrees in the United States, Short-Cycle degrees in China, and three-year diplomas in India

Globalization of the Automotive Industry

Historical Context of Globalization in the Automotive Industry

The automotive industry has been international since its earliest days. Production of Daimler vehicles began under license in France in 1891, England in 1896 and America (New York City) in 1907.[7] Proximity to customers – wealthy individuals during the early days of craft production followed by mass markets during the later days of mass production – has always been a key determinant for the location of vehicle production facilities. The development of Henry Ford's system of mass production around 1910 was a key enabler for offshoring vehicle production facilities. The mass production model of interchangeable parts tremendously reduced the assembly labor content of motor vehicles (and the reliance on craft assembly skills), leading to a proliferation of automotive assembly plants around the world to gain access to new markets.

American automotive firms were pioneers of this early age of globalization. Both Ford and General Motors established their first production facilities outside the United States only one year after each company's founding. This early development of the "build where you sell" philosophy was first driven by the high transport costs of shipping finished vehicles and later bolstered by the increase in trade tariffs during the 1930's. To reduce transport costs, most of the early offshore assembly plants were based on assembly of *Completely Knocked Down* (CKD) kits. Ford could ship eight unassembled Model T CKD kits in the same amount of space that it could ship one completed vehicle. Figure 8 shows the tremendous investment in offshore assembly plants made by Ford, GM and Chrysler prior to 1929.

Figure 8 Offshore CKD Assembly Plants of Ford, GM and Chrysler up to 1928

Company	Number of Plants	Location of Plants (Year opened)
Ford Motor	24	Canada (1904); England (1911); France (1913); Argentina (1915); Argentina (1919); Spain (1919); Denmark (1919); Brazil (1919); Belgium (1919); Sweden (1922); Italy (1922); South Africa (1923); Chile (1924); Japan (1924); Spain (1925); Germany (1925); France (1925); Australia (1925); Brazil (3 locations, 1926); Mexico (1926); India (1926); Malaysia (1926);
General Motors	19	Canada (1907); England* (1908; not a CKD plant); Australia (1923); Denmark (1923); Belgium (1924); England (1924); Argentina (1925); England (1925); Spain (1925); Brazil (1925); Germany (1926); New Zealand (1926); South Africa (1926); Uruguay (1926); Indonesia (1926); Japan (1927); India (1928); Poland (1928); Sweden (1928)
Chrysler	3	Germany (1927); Belgium (1928); England (1928)

Sources: Rhys, D.G. 1972. *The Motor Industry: An Economic Survey*. Butterworths. Maxcy, George. 1981. *The Multinational Automotive Industry*. St. Martin's Press.

The appeal of the CKD model continued to gain traction during the 1930's with the increase in tariffs and other trade restrictions implemented by governments around the world. CKD kits were assessed at a lower tariff in exchange for the investment and employment that the local CKD facility brought. Eventually, the offshore CKD plants gradually began to source increasing volumes of components locally, especially in Europe where tariffs were high and markets were large. Ford and GM followed different paths with their entry into Europe. Ford established wholly-owned subsidiaries with, at least initially, a high degree of control from Detroit. GM, on

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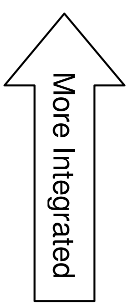
[7] For an excellent historical account of globalization in the automotive industry, see Sturgeon, Timothy and Richard Florida, March 2000. *Globalization and Jobs in the Automotive Industry*. Carnegie Mellon University and Massachusetts Institute of Technology.

the other hand, grew its European operations through acquisitions. GM bought Vauxhall in England in 1926 and Adam Opel AG in Germany in 1929 (subsequently seized by the German government in 1940 and reclaimed by GM in 1948). By the 1950's, both Ford and GM's European operations had achieved high degrees of autonomy – each had their own engineers designing vehicles specifically for the European market (and, in the case of GM, with their own European brands). Each had developed deep local supply chains and no longer relied on CKD units shipped from America. Even within Europe, Ford and GM's operations in the United Kingdom and Germany were largely autonomous and organizationally distinct. The creation of Ford of Europe in 1967 by Henry Ford II, which forced Ford's German and British units to integrate, is viewed as one of the most significant reorganizations in the company's history.

The automotive industry of the mid-1960's was dominated by two large markets – America and Europe – and one emerging market – Japan. Trade in vehicles among these regions was not significant. Americans, for the most part, purchased vehicles manufactured by GM, Ford, Chrysler or American Motors. Within Europe, the national markets were far more distinct than they are today: the French bought French vehicles, the British bought British vehicles, etc. A firm like Adam Opel, although owned by GM, was largely managed as and operated like a German company. The next big automotive production powerhouse – South Korea – had not yet emerged on the scene. Hyundai Motor Corporation was founded in 1967.

The automotive industry underwent a second wave of globalization starting around 1970. International trade in motor vehicles – especially fuel efficient Japanese vehicles – increased with the oil shocks of the 1970's. In the 1980's, foreign direct investment in manufacturing facilities increased. Honda opened the first transplant[8] in Ohio in 1982, beginning a wave of investment that continues today. (The Japanese manufacturers have also followed a similar pattern of investment in transplant production facilities in Europe, although a few years later than in the US.) Starting in the late 1980's but greatly accelerating throughout the 1990's and into the first few years of the 2000's, the world's automotive firms – both OEMs and suppliers – underwent a wave of consolidation through mergers, acquisitions and various degrees of strategic alliances. There are various degrees to the level of business integration among vehicle manufacturers, in order from most integrated to least:



- **Merger/ Acquisition**: Daimler Benz & Chrysler Corp.; Ford & Jaguar; Ford & Volvo; Volkswagen & Seat; Volkswagen & Skoda
- **Controlling Equity Stake**: Ford & Mazda; DaimlerChrysler & Mitsubishi Motors (until July 2005)
- **Non-controlling Equity Stake**: GM & Fiat Auto (until February 2005); GM and Fuji Heavy (until October 2005); DaimlerChrysler and Hyundai (until July 2005)
- **Product Development Agreements / Shared Platforms**: GM Pontiac Vibe and Toyota Corolla shared platform; Peugeot 107 & Toyota Aygo small car program
- **Technology Alliances**: Ford & PSA on diesel engines; GM, BMW and DaimlerChrysler on dual-stage hybrid vehicles; PSA and BMW on small gasoline engines

This evolution has blurred the distinction between domestic and foreign automakers in all countries, including America. Ford owns Jaguar, Volvo, and Land Rover and owns a controlling stake in Mazda; GM owns Saab and Daewoo and has only recently divested equity stakes in several Japanese manufacturers; and Chrysler is owned by DaimlerChrysler AG, a company based in Germany with 74% of its capital stock owned by European investors and whose single

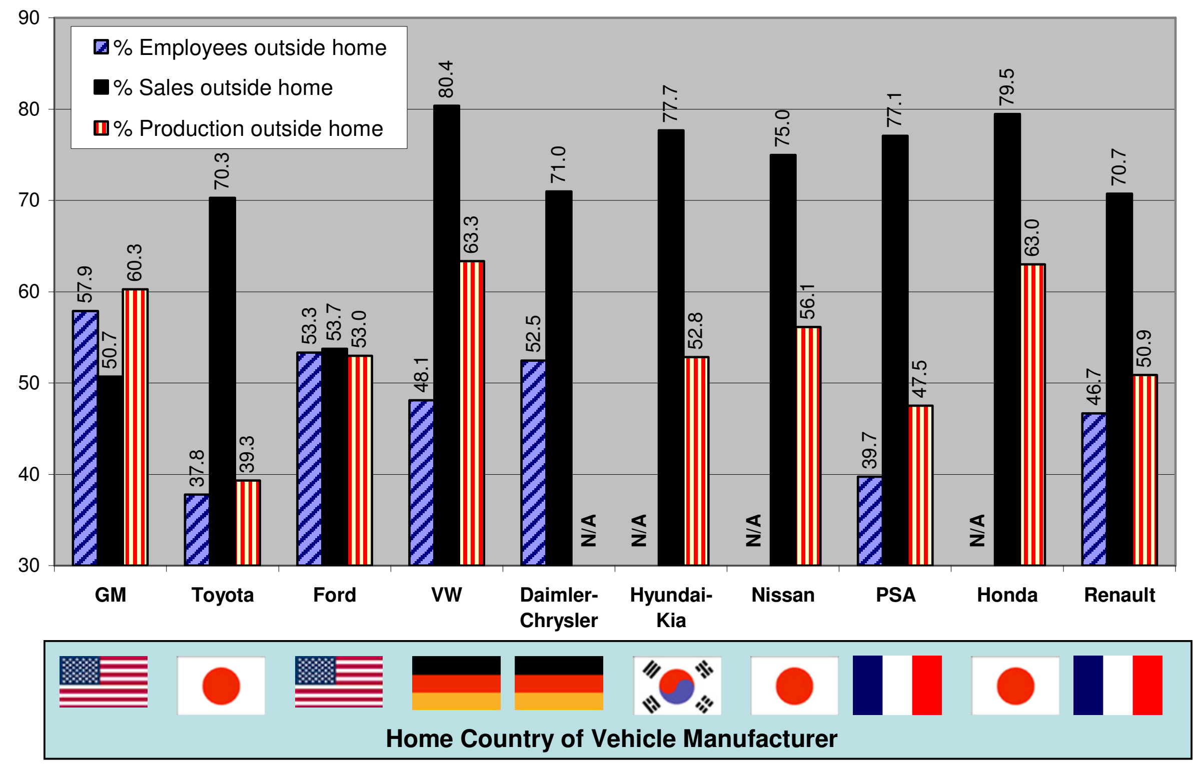
[8] A transplant is a foreign-owned manufacturing facility, such as a Toyota or BMW assembly plant located in the United States.

largest shareholder is the Kuwait Investment Authority[9]. Some of these international relationships are viewed as great successes (e.g., Renault-Nissan), but many others are viewed as failures that destroyed shareholder value (e.g., GM-Fiat, Ford-Jaguar).

Current Degree of Globalization in the Industry: Production, Employment and Sales
Although the web of global business relationships in the industry has disintegrated to some degree (e.g., the termination of the GM-Fiat relationship), today's automotive industry is more globally integrated than ever. Figure 9 shows the percent of employment, sales and production outside of the home country for the world's top ten vehicle manufacturers (as ranked by 2005 global sales). These ten vehicle manufacturers account for about 83% of global vehicle sales. We can draw many conclusions from these data:

- Each of the world's top ten global automakers sold more vehicles outside their home markets than within their home markets. GM sold more than half its vehicles outside the United States for the first time in 2005. For the two US-based automakers, Ford and GM, the proportion of sales outside their home market (USA) is slightly more than half. For each of the other eight vehicle manufacturers studied, the proportion of sales outside their home markets ranges from roughly 70% to 80%.
- For all ten companies where data were available, the lowest proportion of sales, production or employment outside the home country is around 38%. Furthermore, the proportion of sales, production and employment outside the home country is growing for all companies shown. GM and Ford are essentially shrinking in their home market (USA) while their competitors are growing their base in the United States.

Figure 9 Percent of Employees, Sales and Production Outside Home Country for Top 10 Global Automakers



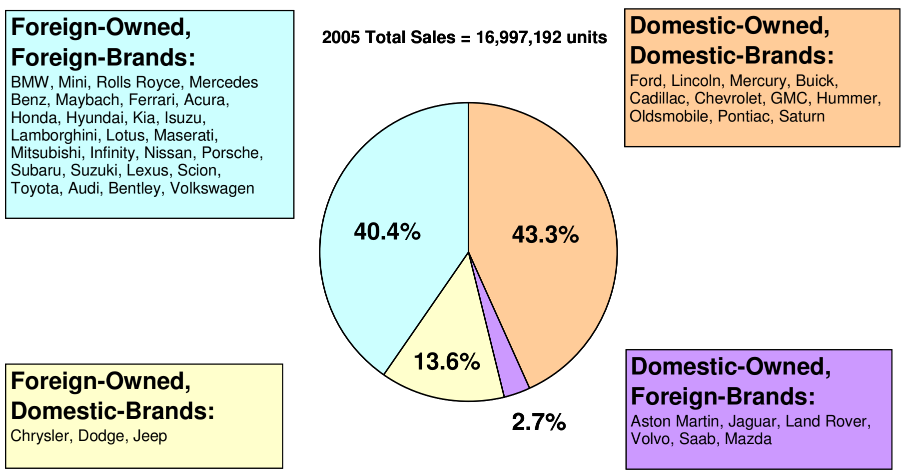
Source: Company annual reports and market literature, except for Ford global and USA production data from Automotive News; Ford USA sales from Automotive News.

[9] DaimlerChrysler 2005 Annual Report.

Notes: Renault data are based on first half 2006. All other data for 2005. Production and sales data are based on vehicle units, rather than value. PSA is PSA Peugeot Citroën of France.

Figure 9 shows the degree of globalization from the perspective of the top firms. Another way to address the globalization question is from the perspective of markets: how open are the major national and regional automotive markets to foreign-brand or foreign-made products? Figure 10 shows 2005 sales in the US market divided into four-categories: foreign-owned foreign-brands (e.g., Honda); foreign-owned domestic brands (e.g., Chrysler); domestic-owned foreign brands (e.g., Volvo) and domestic-owned domestic brands (e.g., Chevrolet). Viewed from this perspective, 54% of the vehicle sold in the United States are sold by foreign-owned firms.

Figure 10 US Vehicle Sales by Category



Data Source: Automotive News

Table 1 contrasts the US data with Western Europe, Japan and Korea. The US market is the most open; however, other developed markets are increasing both foreign-brand and foreign-ownership penetration. The Japanese automakers have followed a similar pattern of building transplants in Europe.[10] The 26.6% foreign-brand penetration for Western Europe includes Chrysler vehicles, but not Opel (owned by GM) vehicles. The 38.2% foreign-ownership penetration includes Opel vehicles, but not Chrysler vehicles. The 9.0% figure for Japan includes Mazda vehicles (controlled by Ford), and the 26.2% figure for South Korea includes Daewoo vehicles (controlled by GM).

Table 1: Foreign Penetration in Four Developed Markets, 2004

Country or Region	Foreign-Brand Penetration	Foreign-Ownership Penetration
United States	41.3%	51.2%
Western Europe	26.6%	38.2%
Japan	4.2%	9.0%
South Korea	2.3%	26.2%

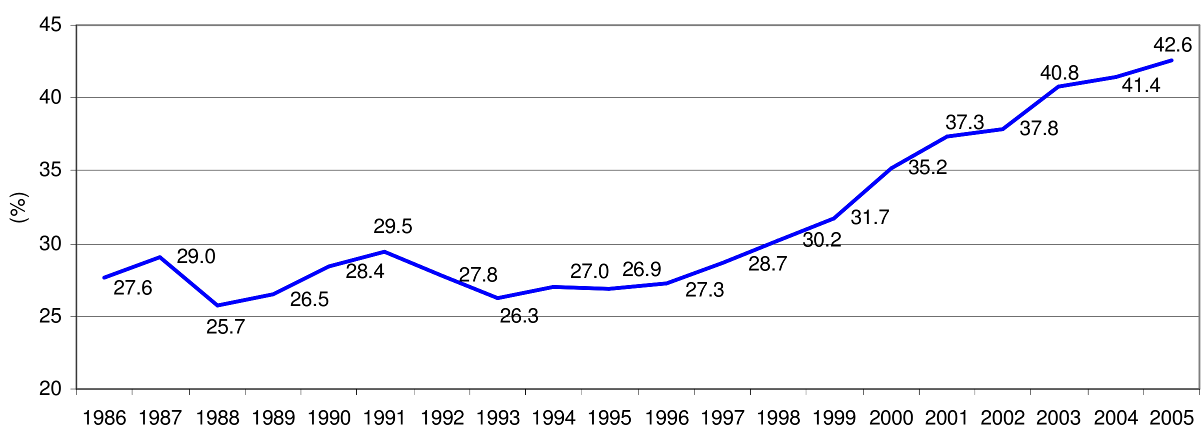
Data Source: European Automobile Manufactures Association (ACEA), Japan Automobile Manufacturers Association (JAMA), Korea Automobile Manufacturers Association (KAMA)

[10] According to JAMA, Japanese automakers operated 14 transplants (assembly plants) in Europe in 2003 producing 1.25 million vehicles (more than double 1995 transplant production). Japanese automakers operated 15 R&D centers in Europe in 2003.

Globalization of the US Automotive Market
In the US market, competition from foreign automakers has steadily increased providing more choice to US consumers. In particular:

- Several foreign brands have entered or dramatically increased their share in the US market since 1980. Foreign automakers have attacked their US competitors on all fronts. Honda moved upscale with the introduction of the Acura brand in the United States in 1986. Toyota followed with the introduction of the Lexus brand in 1989, the same year that Nissan launched the Infiniti brand.
- New market segments are appearing. Toyota moved toward the downscale/hip youth segment with introduction of the Scion brand in 2004. DaimlerChrysler introduced the Maybach as a new super luxury car for over $300,000.
- Manufactures are expanding their model offerings to cover all market segments. Low end producer VW tested the US market with high-end Phaeton, while high end producers Audi and BMW are introducing lower cost models (Audi A3, BMW 1-series).
- The threat of re-entrants looms large as well. Speculation has swirled around both French automakers – Renault and PSA Peugeot Citroën – reentering the US market.
- The recent emergence of the Koreans. In 1986, Hyundai entered the US market but retreated in the early 1990's due to quality problems. Over the past five years, US sales of Hyundai vehicles have come roaring back as quality greatly improved. Hyundai acquired majority ownership in Kia Motors in 1998 and Hyundai/Kia US market share has increased steadily to 4.3% for 2005.

Figure 11 Foreign-Brand Market Share in the United States: 1986-2005

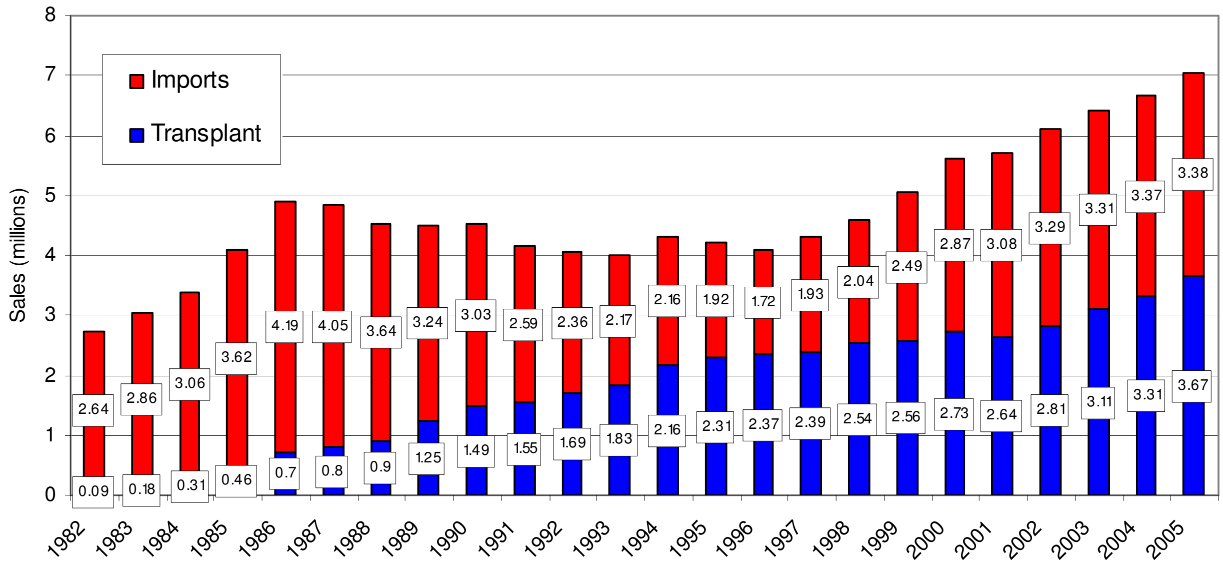


Source: Automotive News Data
Note: Includes domestic-owned foreign-brands, such as Volvo (Ford) and Saab (GM).

Figure 11 shows that sales of foreign-brand automakers have increased in the United States over the past 25 years. The gain in market share of the foreign brands has come at the expense of the domestic brands. The combined US market share of the traditional Big 3 automakers has steadily declined since the mid-1980's to 58.5% in 2005. In 1985, GM led the US market with just over 40% market share, a figure that has steadily declined to 25.8% for 2005 sales. In 1985, Ford was number two with about 22% market share. Ford share crept up to about 26% in the mid-1990's, but then slid to 18.2% for 2005 sales. DaimlerChrysler's 2005 US market share of 14.5% is nearly identical to the 1985 market share for the Chrysler Corporation. The combined Japanese-brand share has steadily increased from just under 20% in 1985 to almost 34% today.

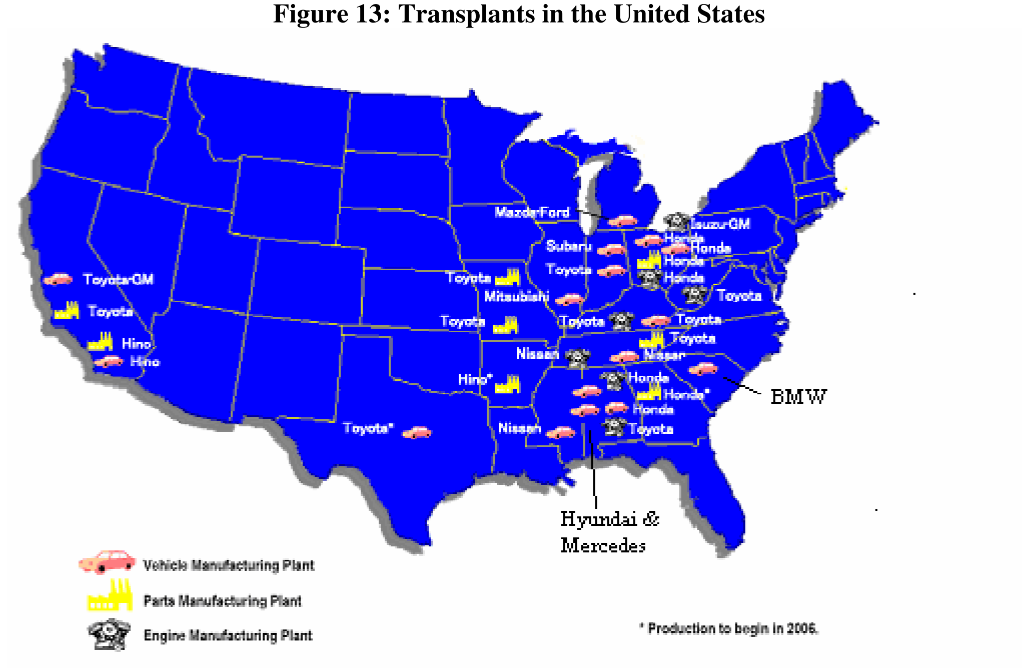
US sales of foreign brand vehicles were driven by imports through the mid-1980's, and then supplemented by transplant-produced vehicles, as shown in Figure 12. There are currently 17 transplants in the United States – 14 from Japanese Original Equipment Manufacturers (OEMs), one Korean OEM (Hyundai) and two German OEMs (Mercedes Benz and BMW), as shown in Figure 13.

Figure 12 US Sales of Foreign-Brand Vehicles Split by Transplant-Produced and Imports



Source: Center for Automotive Research study prepared for Association of International Automobile Manufacturers, Inc., Automotive News Data, US. Dept. of Commerce, IMVP

Figure 13: Transplants in the United States



Source: Japan Automobile Manufacturers Association (JAMA), IMVP

As of early 2005, the US transplants employed about 65,000 people and accounted for a cumulative investment of over $27 billion. However, these figures are rapidly increasing. In April

2006, Toyota announced a major expansion of its Indiana plant. In June 2006, Honda announced it will build a new assembly plant in Indiana to begin production in 2008. Kia (a brand of Hyundai) broke ground for a second assembly plant in Georgia in October 2006. On the other hand, the Detroit 3 manufacturers are closing US plants and reducing production volumes (as described in the next chapter). In 2006 Ford closed its St. Louis and Atlanta assembly plants and GM closed its Oklahoma City plant. As of October 2006, the assembly plant footprint in North America is as shown in Table x.

Table 2 North American Assembly Plant Footprint as of October 2006

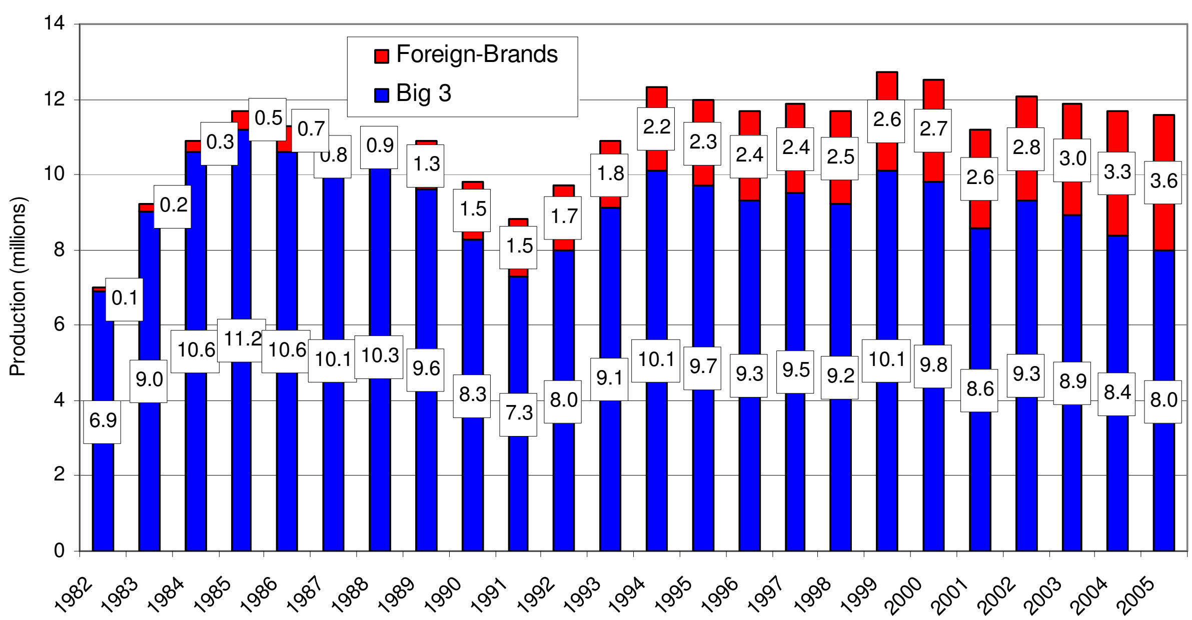
Manufacturer	USA	Canada	Mexico	North America Total
GM	17	1	3	21
Ford	10	2	2	14
DaimlerChrysler	8	2	2	12
Other OEMs	14	3	7	24
Total	49	8	14	71

Sources: Automotive News, company reports

Notes: Locations that include two assembly plants, such as Honda in Lincoln, Alabama, and Toyota in Princeton, Indiana, counted only once above. Mercedes plant in Alabama included with DCX USA. This accounts for the difference between 14 US transplants shown above and 17 cited previously. Other OEMs USA includes NUMMI Toyota-GM facility and AutoAlliance Ford-Mazda facility. Other OEMs Canada includes CAMI GM-Suzuki facility.

Figure 14 shows US light vehicle production since 1982 split by domestic plants and transplants. Overall US production has hovered around 12 million vehicles since 1994. In this sense, the US automotive industry remains relatively healthy. Figure 14 also demonstrates a gradual but relentless substitution from domestic plants to the transplants, which produced a record 3.58 million vehicles in the United States in 2005. As the new Hyundai plant in Alabama and the new Toyota plant in San Antonio ramp up production, this figure will approach 4 million units in 2006. We have now reached the point where roughly one out of every three vehicles built in the United States is from a foreign company.

Figure 14 US Light Vehicle Production (Domestic and Transplant): 1982-2005



Source: Automotive News Data

All major vehicle manufacturers engineer and manufacture engines and transmissions following a "powertrain is core business" mantra. (OEMs are, however, increasingly sharing engine and transmission programs or sourcing from other manufacturers.) A Center for Automotive Research report estimates that foreign-brand automakers had engine production capacity of 3.5 million units in 2003, accounting for 30.5% of the total engine production capacity in the United States.[11] Honda has major engine manufacturing facilities in Anna, Ohio and Lincoln, Alabama; Nissan has an engine plant in Decherd, Tennessee; and Toyota has engine plants in Georgetown, Kentucky, Huntsville, Alabama, and Buffalo, West Virginia. A similar economic assessment report measured total engine production capacity of the foreign-brand automakers at 1.5 million units in 1996. Hence, over an eight year period, foreign engine production capacity grew by 133%.

The process of globalization in the United States has been disruptive for several automakers and parts suppliers; however, it has generated tremendous benefits for US consumers. Americans have more vehicle model choices than ever before. Manufacturing productivity and quality levels have improved and converged among all automakers. Vehicle prices have fallen in real terms at the same time that significant product enhancements have occurred (such as advanced safety, environmental and performance features).

Globalization of the Automotive Supplier Industry

The world's component suppliers – a critical component to the automotive value chain – have also undergone a relentless process of globalization since the 1990's. Nowadays, vehicle manufacturers "shop at the global mall" – that is, they source components from locations around the globe and regardless of the headquarters location of the supplier. Suppliers have been globalizing along two levels: suppliers have followed their traditional home market customers to other parts of the world (e.g., Denso, a large Japanese supplier, has followed Toyota to the United States), and suppliers have focused on winning business from OEMs based in other parts of the world. We have witnessed the emergence of "mega-suppliers" through merger, acquisition and spin-off.

Table 3: Top 20 Global Automotive Suppliers by 2005 Sales to Automotive OEMs

Company	Home Region	2005 Sales to Auto OEMs (US$ billion)	% North America	% Europe	% Asia	% ROW
Robert Bosch GmbH	EU	28.4	17	69	14	
Denso Corp.	JP	22.9	21	14	64	1
Magna International Inc.	NA	22.8	56	43		1
Delphi Corp.	NA	22.6	71	21	7	1
Johnson Controls Inc.	NA	19.4	46	47	7	
Aisin Seiki Co. Ltd.	JP	17.9	18	8	73	1
Lear Corp.	NA	17.1	54	38		8
Visteon Corp.	NA	15.9	61	24	12	3
Faurecia	EU	14.0	11	81	4	4
TRW Automotive Inc.	NA	11.7	38	54		8

Source: Automotive News

[11] See Center for Automotive Research. March 2005. *The Contribution of the International Automotive Sector to the US Economy: An Update*. Study prepared for the Association of International Automobile Manufacturers, Inc.

Table 3 shows how each of the world's top ten suppliers have significant sales volumes outside of their home regions. An analysis of the world's top 100 global suppliers (based on 2004 data) reveals that 38.3% of total sales were to customers outside their home market, with North American suppliers the most global:

- 41.2% of the sales of the North America suppliers in the top 100 global suppliers were to customers outside North America
- 38.2% of the sales of the Japanese suppliers in the top 100 global suppliers were to customers outside Japan
- 35.2% of the sales of the European suppliers in the top 100 global suppliers were to customers outside Europe

A study by the Federal Reserve Bank of Chicago analyzed the ELM database, which tracks who supplies whom in the US auto industry. In 1997, all of the transplants had at least 60% of their suppliers as domestic suppliers, as shown in Table 4. The study also sheds light on the significance of geographic proximity of suppliers to their customers.

Table 4: 1997 Analysis of Suppliers to Transplants:
Number of Suppliers, Median Distance to Assembly Plant, and Percentage Domestic

Assembly Company	Location	Start-Up Year	Number of Suppliers	Median Distance (miles)	% Domestic
Honda	Marysville & East Liberty, OH	1982	507	251	65
Toyota	Georgetown, KY	1988	452	285	69
Subaru-Isuzu	Lafayette, IN	1987	292	245	60
Diamond-Star (Mitsubishi-Chrysler JV)	Normal, IL	1988	286	309	63
AutoAlliance (Ford-Mazda JV)	Flat Rock, MI	1987	360	242	71
Nissan	Smyrna, TN	1983	460	423	70
BMW	Spartanburg, SC	1994	119	477	75
Mercedes Benz	Vance, AL	1997	77	610	68
NUMMI (Toyota-GM joint venture)	Freemont, CA	1984	178	1966	60
Saturn (GM)	Spring Hill, TN	1990	300	462	81
Ford (1970-80)	Dearborn, MI	N/A	222	405	89
Ford (1983-1993)	Dearborn, MI	N/A	301	200	77

Source: *Agglomeration in the US auto supplier*, Thomas Klier, Federal Reserve Bank of Chicago

A joint study by McKinsey and the Original Equipment Suppliers Association (OESA) in 2004 surveyed 57 large suppliers doing business in North America, as shown in Table 5.

Table 5: McKinsey-OESA Supplier Survey Results: 2003 Customer Mix and 2008 Aspiration

	European Suppliers		Japanese Suppliers		North American Suppliers	
Customers:	2003	2008 Aspiration	2003	2008 Aspiration	2003	2008 Aspiration
Korean OEMs	0	4	0	2	1	5
Japanese OEMs	6	17	60	55	8	14
European OEMs	14	18	2	5	11	24
North American OEMs	79	61	38	38	80	57

Both European suppliers and North American suppliers want to reduce their reliance on North American OEM customers from roughly 80% in 2003 to roughly 60% in 2008. Japanese suppliers are content with their current customer mix, which includes about 40% North American OEMs. Diversification of a supplier's customer base away from its traditional home region seems to make good financial sense. Some reports indicate that OEMs that are less reliant on Detroit 3 business have better financial performance.[12]

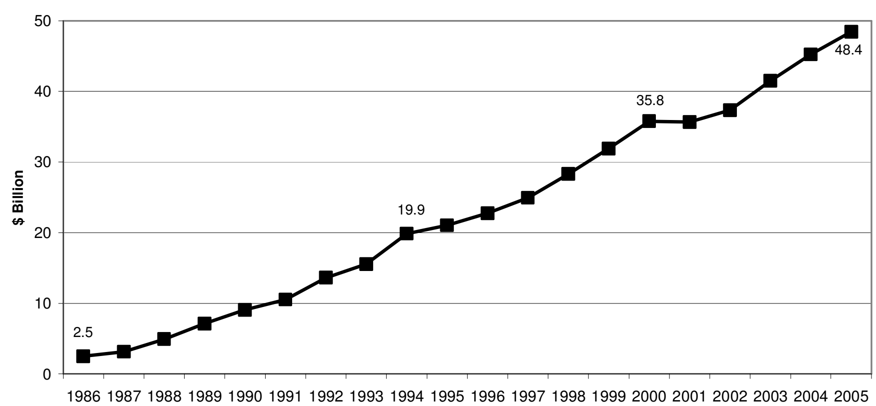
This complexity of the global supply base makes measuring the local content of most modern automobiles nearly impossible. US vehicles contain thousands of components from European and Japanese suppliers, each which are built up from smaller components and materials also supplied around the world. Consider for example, the 2005 Dodge Dakota shown in Figure 15 below:

Figure 15: Some Non-US Suppliers to the 2005 Dodge Dakota

Source: Automotive News

Foreign-brand automakers are major purchasers from US suppliers. The previously-referenced Center for Automotive Research report estimates that in 2003, foreign-brand automakers purchased $66.7 billion worth of goods and services from suppliers in the United States. Of this total, $49.1 billion was for manufacturing / production purposes, and $17.6 billion was for non-production purposes (such as engineering and design, sales, distribution, finance and port services). The volume of foreign automaker purchasing from US suppliers has been growing very rapidly, as shown in Figure 16.

Figure 16 Japanese Automaker Purchases of US Parts: 1986-2005



Source: Japan Automobile Manufacturers Association (JAMA)

[12] See Casesa, John et al. *The Recapitalization of Detroit*. Merrill Lynch. October 18, 2005.

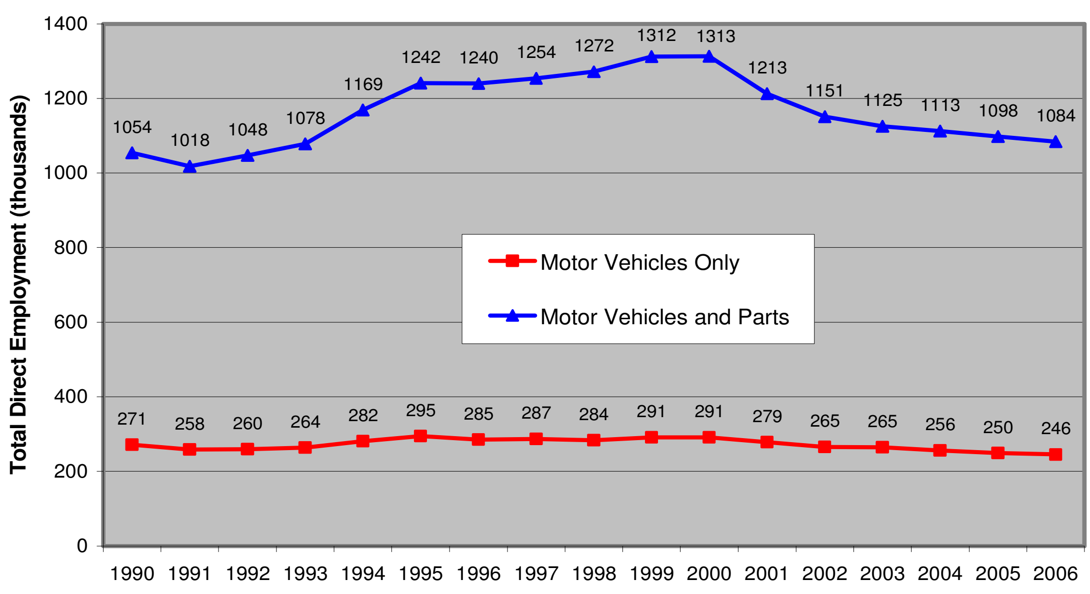
US Engineering Workforce in the Automotive Industry

Overall Employment in the US Auto Industry

The automotive industry is one of the leading employers in the United States. According to data from the Bureau of Labor Statistics (BLS), the automotive industry directly employs roughly 1.1 million people among vehicle manufacturers and suppliers in *manufacturing* (not sales, service, etc.). Figure 17 shows total automotive employment for the vehicle manufacturers (in red) and the vehicle manufacturers and parts manufacturers (in blue). Overall employment in the parts sector has declined slightly more (17.4%) than for the vehicle manufacturers (15.5%). However, these are dramatic times for the US automotive workforce. Consider the following[13]:

- In January 2006, Ford announced its *Way Forward* plan, which included plans to idle 14 manufacturing facilities reducing employment by 25,000-30,000. The plan called for reducing North American production capacity by 1.2 million units, or 26%, by 2008. The company also announced a 10% reduction of salaried cost in North America, and a related headcount reduction of 4000 people by first quarter 2006. Recently, Ford has announced plans to accelerate the *Way Forward* restructuring to slash North American employment by 44,000 and reduce 4th quarter production by 21%.
- In 2005, GM announced plans to close 12 US assembly plants by 2008 and reduce its manufacturing workforce by 30,000. This will reduce GM's US manufacturing capacity by about one million units by 2008. GM already reduced its US manufacturing capacity by around one million units between 2002 and 2005. GM's US salaried workforce (including contract staff) had been reduced by 33% since 2000.
- However, at the same time, Hyundai, Toyota and Honda are building new plants and increasing their total employment and R&D employment in the United States.

Figure 17 US Automotive Industry Employment 1990-2006



Source: US Bureau of Labor Statistics.
Note: 2006 data is for first half 2006. Data are NAICS code 3361 for motor vehicles and code 3361,2,3 for motor vehicles and parts.

[13] See Ford and GM 2005 annual reports.

US automotive suppliers are also under tremendous financial pressure due to production cuts at the domestic manufacturers and downward price pressure from their OEM customers coupled with upward cost pressure for steel, aluminum, resins and other materials used to make automotive components. Several US automotive suppliers have filed for bankruptcy over the past two years, as shown in Table 6. Many of these bankruptcies have been accompanied by substantial employment losses.

Table 6 Recent Bankruptcies at US Automotive Suppliers

Company	Date of filing	Total assets	Employees
Delphi Corp., Troy, Mich.	Oct. 8, 2005	$17.1 billion	185,000
Federal-Mogul, Southfield, Mich.	Oct. 1, 2001	$10.1 billion	50,000
Dana Corporation, Toledo, Ohio	March 3, 2006	$7.9 billion	46,000
Collins & Aikman Corp. Troy, Mich.	May 17, 2005	$3.2 billion	23,900
Hayes Lemmerz, Northville, Mich.	Dec. 5, 2001	$2.8 billion	15,000
Tower Automotive, Novi, Mich.	Feb. 2, 2005	$2.6 billion	12,891
Dura Automotive Systems, Rochester Hills, Mich.	October 30, 2006	$2.0 billion	15,200
Venture Holdings, Fraser, Mich.	March 28, 2003	$1.4 billion	12,980
Oxford Automotive*, Troy, Mich.	Dec. 7, 2004	$1.0 billion	3,800

Source: BankruptcyData.com, Automotive News, Company Reports
Note: Oxford Automotive also filed for bankruptcy on Jan. 18, 2002

Engineering Employment in the US Automotive Industry

Determining a precise estimate of the number of automotive engineers in the United States through BLS data poses a challenge. There are three NAICS codes for the automotive industry: NAICS codes 3361 (Motor Vehicle Manufacturing), 3362 (Motor Vehicle Body and Trailer Manufacturing) and 3363 (Motor Vehicle Parts Manufacturing). Table 7 shows the US employment levels for various types of engineers for the three automotive NAICS codes. However, engineers whose primary function is R&D – all of the industry's product engineers – are not included in these data. R&D engineers in the automotive industry fall under NAICS 5417 Scientific Research and Development Services. Therefore, the data in Table 7 mostly reflect manufacturing engineers.

Table 7 US Employment of Automotive Engineers (Does not Include R&D Engineers)

Occupational Code	NAICS 3361: Motor Vehicle Manufacturing	NAICS: Motor Vehicle Body and Trailer Manufacturing	NAICS 3363: Motor Vehicle Parts Manufacturing	Total of All Three NAICS Codes
Engineering Manager	610	570	3,960	5,140
Industrial Engineer	3,390	1,240	14,460	19,090
Mechanical Engineer	1,920	1,360	9,300	12,580
Electrical Engineer	150	110	910	1,170
Engineers, All Other	n/a	180	7,200	7,380
Total	**6,070**	**3,460**	**35,830**	**45,360**
All Occupations	**256,700**	**168,840**	**693,120**	**1,118,600**

Source: US Bureau of Labor Statistics, Occupational Employment and Wages Estimates for May 2005.

A BLS career brief on *Motor Vehicle and Parts Manufacturing* compiled using May 2004 data estimates all other engineering employment in the same three NAICS codes at 18,000, which is significantly higher than the roughly 8,600 shown in Table 7. Using this figure, we can estimate the 2005 total number of manufacturing engineers in the automotive industry at 55,000.

To estimate the number of product engineers, we can take a bottom-up approach. Table 8 shows that the total estimated number of engineers and technicians working for vehicle manufacturers (not parts makers) in the United States is roughly 34,000. Assuming the same ratio of supplier engineers to vehicle manufacturer engineers as the ratio of supplier employees to vehicle manufacturer employees (roughly three to one), we can estimate that there are at least 100,000 engineers and technicians supporting the automotive supply base in the United States. One needs to consider that many firms that supply the auto industry do not fall under an auto industry SIC or NAICS, firms such as Motorola, Siemens, and IBM. Therefore, the estimate of 100,000 engineers and technicians supporting the automotive supply base in the United States is likely to be on the low end.

Table 8 US Engineering/Technical Employment for Major Vehicle Manufacturers

Company	Current Number of Engineers & Technicians	Projection
General Motors	11,500	Decreasing
Ford Motor Company	12,000	Decreasing to 10,000
DaimlerChrysler *	6,500	Steady
Japanese	3593	Increasing Rapidly
Korean (Hyundai-Kia)	200	Increasing Rapidly
German (BMW)	150	Increasing
Total	About 34,000	

Source: Company Interviews, JAMA, company reports
Note: * Technicians may be included. Japanese data includes designers.

Combining Table 7 and 8 we can form an estimate that a total of 189,000 product and manufacturing engineers are employed by the automotive industry in the United States, as shown in Table 9. This estimate is probably on the low side due to the engineers that work for the automotive businesses of large firms that serve many industries, such as DuPont and Siemens.

Table 9 Estimate of US Automotive Engineering Employment

Industry Sector	Product Engineers	Manufacturing Engineers	Total
OEMs	34,000	10,000	44,000
Suppliers	100,000	45,000	145,000
Total	134,000	55,000	189,000

Engineering Wages in the US Automotive Industry

The BLS database also provides insight into the wages of engineers in the US auto industry. The annual mean salary for the weighted average of NAICS codes 3361 (Motor Vehicle Manufacturing), 3362 (Motor Vehicle Body and Trailer Manufacturing) and 3363 (Motor Vehicle Parts Manufacturing) for May 2005 yields the following:

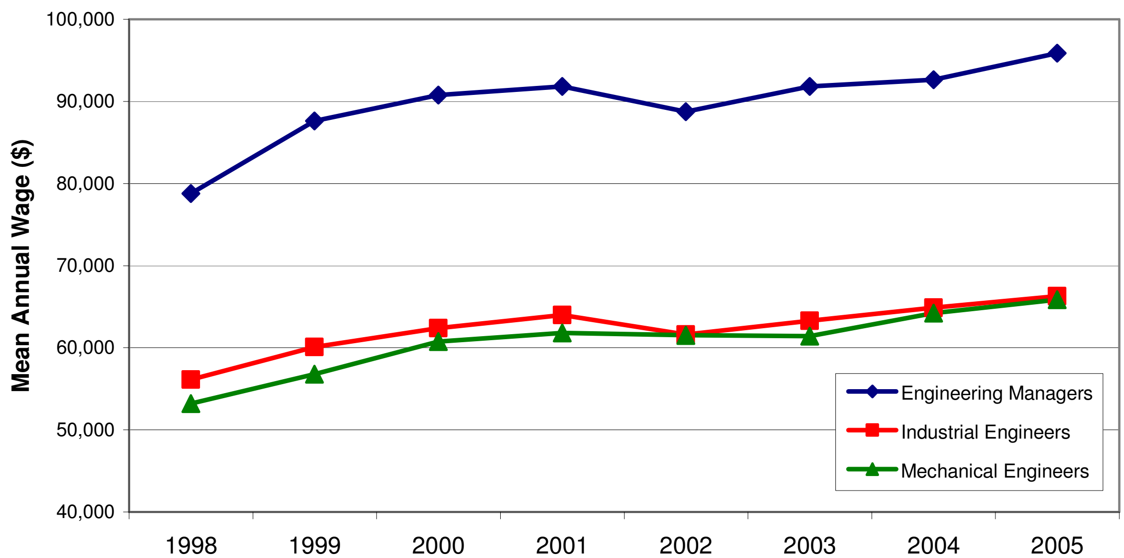
- Engineering Managers: $95,872
- Industrial Engineers: $66,284
- Mechanical Engineers: $65,861

The National Science Foundation Report *Scientists*, *Engineers and Technicians in the United States: 2001* estimates 2001 mean annual wages as follows:

- Managers of SET personnel: $90,086
- Scientists: $61,637
- Engineers: $63,107
- Technicians: $46,947

Figure 18 shows mean annual wages for engineering managers, industrial engineers and mechanical engineers extracted from BLS occupational wage and employment estimates over the past eight years. The figure shows that US engineering wages have been gradually increasing. However, this figure should be viewed with some caution since the survey is designed for cross-sectional analysis rather than time-series analysis.

Figure 18 Annual Mean Wages for Engineering Occupations in the US Automotive Industry



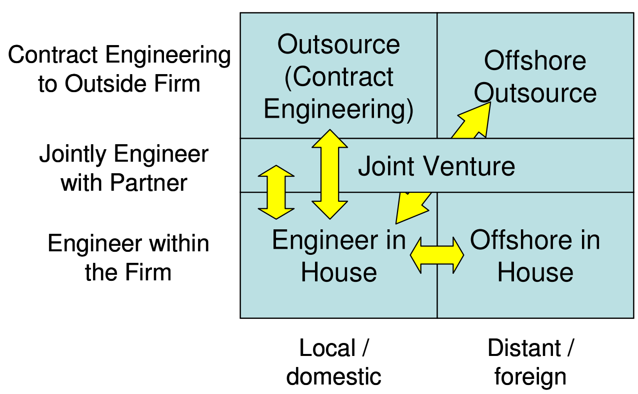
Source: Data extracted from US Bureau of Labor Statistics, Occupational Employment and Wages Estimates
Notes: 1998-2001 data are for SIC 3710 Motor Vehicles and Equipment. 2002-2005 data are a weighted average of NAICS 3361 Motor Vehicle Manufacturing, NAICS 3362 Motor Vehicle Body and Trailer Manufacturing and NAICS 3363 Motor Vehicle Parts Manufacturing.

Dynamics of the Automotive Engineering Global Footprint

Definition of Offshoring

This paper addressed the following question: Is engineering offshoring occurring in the automotive industry? The definition of *offshoring* is ambiguous and frequently used interchangeably with *outsourcing*. Figure 19 shows one way of thinking about the terms *offshoring* and *outsourcing*. To illustrate, one can view Figure 19 from the perspective of General Motors. GM's Technical Center in Warren, Michigan, can outsource certain technical functions to one of the many Detroit-area contract engineering firms, such as MSX International or Kelly Services. Such contract engineers frequently work side-by-side with GM engineers within the Warren Tech Center – truly local outsourcing. GM can also share engineering functions with one of the 12 GM engineering centers outside the United States, and shift work among those centers as it views appropriate. GM can also source engineering work to an oversees outside firm, such as Wipro Technologies in India. Finally, GM can share engineering functions with a joint venture partners, as it does with the Pan-Asian Technical Automotive Center (PATAC) in Shanghai, a joint venture between GM and their Chinese partner, Shanghai Automotive Industry Corporation (SAIC).

Figure 19 Framework for Defining Offshoring and Outsourcing



The key point is that all vehicle manufacturers employ engineers in all four quadrants of the matrix in Figure 19. Management can and will shift functions to various quadrants to optimize overall engineering efficiency – that is, to optimize their engineering resources, both within and outside the firm, both local and distant. This is why the arrows in Figure 19 point in both directions: GM can choose to bring an engineering function back to Warren just as easily as it can send it out of Warren. The term *offshoring* is frequently used to imply a *replacement* of US workers with foreign workers. This replacement phenomenon is certainly possible within the framework of Figure 19, but it is only one part of a much broader story.

The Dynamics of Automotive Engineering Footprint Management

As discussed earlier in the report, there are two fundamental categories of engineers in the automotive industry: product engineers and manufacturing engineers. The footprint strategy – that is, the strategy of where to locate these different types of engineers for a given firm – is driven by a variety of factors. Interviews with industry managers point to four critical factors that both vehicle manufacturers and suppliers consider when determining their footprint strategy: customer, cost, capability and government policy. These factors are shown in Figure 20.

As manufacturing engineers are typically tied to the location of production, the production footprint can be used as a proxy for the manufacturing engineering footprint. In other words, the factors that determine the location of production facilities will also determine the location of manufacturing engineers. The factors that determine the location of product engineers are similar to the factors for manufacturing engineers, but with different weightings. For example, government policy has played a stronger role in determining an automotive firm's production footprint than it has for its R&D footprint. In particular, trade policy had a strong role in shaping the "build where you sell" strategy as described in the globalization chapter. This is shown in Figure 21.

Figure 20: 3C+G Global Footprint Model for the Automotive Industry

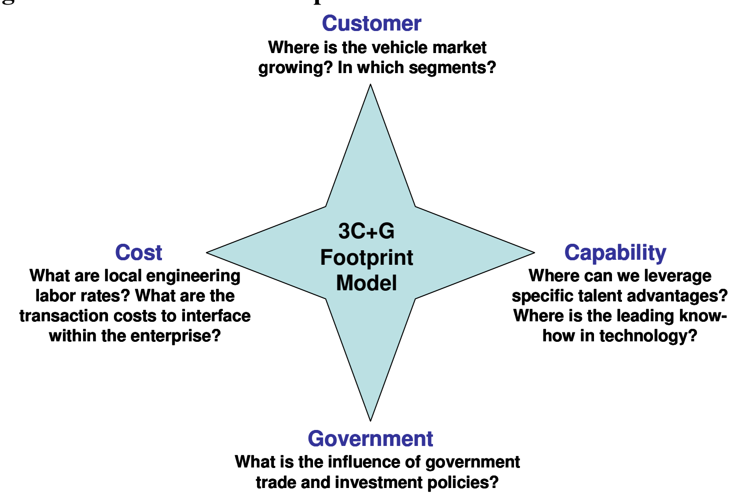


Figure 21 Impact of 3C-G Factors on Manufacturing Engineering versus Product Engineering Footprint

Factor	Influence on Manufacturing Engineering Footprint	Influence on Product Engineering Footprint
Customer	High	Medium
Cost	Medium	Medium
Capability	Low	High
Government	High	Low

The Value of Proximity

Before assessing the impact of each of the 3C-G factors on manufacturing and product engineering, it is worth assessing the value of proximity in the automotive engineering world. Why is it valuable for vehicle manufacturers to "build where you sell"? Is it also valuable for vehicle manufacturers to "engineer where you sell"? Does "the world is flat" make sense in the automotive industry?

As described in the globalization chapter, minimizing transport costs was a key motivator for localizing vehicle production facilities. Automobiles are expensive to transport, although the transport cost relative to the average vehicle cost has declined. Trade policy has always played a key role in the localization of production. Trade policy was a key factor contributing to the rise of the transplants in the United States. In the early 1980's, the Big 3 automakers and the United Auto Workers (UAW) pressured the US government to limit the import of Japanese vehicles. In response to this pressure the Japanese Ministry of International Trade and Industry (MITI) announced a Voluntary Restraint Agreement (VRA) that limited Japanese exports of vehicles to the United States. The VRA's backfired, providing further incentive for the development of the transplants since they only applied to export vehicles, not to vehicles built in the United States. Furthermore, the VRAs were based on volume of vehicles rather than value, therefore, providing an incentive to move upscale and develop luxury vehicles for export to the U.S. (e.g., bringing Acura, Lexus and Infiniti to the United States). The Japanese manufacturers also reaped enormous profits on their high-demand, VRA-limited-supply vehicles.[14] The net effect was that the VRAs had consequences completely contrary to the protection that domestic manufacturers sought.

Reducing currency risk is also a motivation for localizing production. Recent declines in the US dollar versus the Euro hurt European manufacturers with large volumes of exports to the United States, such as BMW and Mercedes. Currency risk factored into the decisions of both BMW and Mercedes to build US transplants in the mid-1990's. Foreign exchange rates were also a tremendous driver of the rise in production volume from Japanese transplants in the United States during the late 1980's. During the month of February 1985, the yen traded at an average daily rate of 260.5 to the dollar. During the month of May 1987, the yen trade at an average daily rate of 140.5 to the dollar, greatly reducing the purchasing power of American consumers for imported Japanese products. This dramatic shift in the dollar-yen rate provided further incentive for Japanese OEMs to invest in US transplants. Localizing production is an important hedge against currency risk.

Localizing production also provides benefits to corporate reputation in the local community and enhances the local political influence of the company. Honda has been manufacturing in Ohio for well over two decades, and many locals say that it feels like an American company. Some buyers are more likely to buy a foreign brand vehicle if it is built in America. Bringing an automotive assembly plant to a community is a politician's dream. Many automotive assembly plants, even the modern ones, employ four thousand people directly and even more indirectly.[15] Assembly plants tend to be located at the confluence of major highways – they are very visible to voters in the local community. Most of the recent transplants built in the United States have also been offered tax breaks or other fiscal incentives to attract the investment from state and local governments. In some cases, local governments have offered increasingly lucrative fiscal incentives to secure the winning bid that brings the plant to their community. The combination of all these factors contributes to the high impact of customer location on production location (and, therefore, manufacturing engineering location) as shown in Figure 22.

The impact of customer on the product engineering footprint is important, but significantly less than on the manufacturing engineering footprint. There are two key reasons to "engineer where you build": localization engineering and engineering products that are primarily consumed by the local market. Localization engineering is the process of adapting a vehicle engineered in country A to meet the unique regulatory and country requirements of country B. For example, a Buick engineered predominantly at GM's Warren, Michigan, engineering center that is manufactured

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[14] Estimates of the level of profits range from $4 - $7 billion per year for 1981 to 1985. See, for example, *Foreign Policy and the US Automotive Industry: By Virtue of Necessity?* Michael Smitka, Business and Economic History, Winter 1999 or *Windfall Profits and Vertical Relationships: Who Gained in the Japanese auto industry from VERs?,* John Ries, Journal of Industrial Economics, Oxford, Sept. 1993

[15] The average US transplant assembly plant employs 3800.

and sold by Shanghai GM, GM's joint venture operation in China, may undergo several local engineering changes that require different components. For example, Chinese customers may prefer more chrome in the vehicle interior. Those engineering changes are best made by GM's Chinese engineers in China.

A second circumstance where it makes sense to "engineer where you sell" is when a vehicle is sold predominantly to a local market. The United States is the largest market for pickup trucks in the world. It is very unlikely that GM or Ford will every shift their engineering center for pickup trucks to outside the United States. On the other hand, Honda, which increasingly sells pickup trucks (with its Ridgeline vehicle) and other light trucks (such as the Acura MDX sport utility vehicle) to the US market, is shifting the engineering function for those vehicles to the United States – a case of "engineer where you sell". Honda has 10,000 engineers in Japan and about 1300 engineers in Ohio. The engineers in Japan work on most Honda vehicle programs, almost all powertrain programs, and almost all of Honda's advanced R&D, such as hybrid powertrain systems or fuel-cell vehicles. However, increasingly the 1300 engineers in Ohio are taking on responsibility for entire vehicle programs, especially for vehicles sold predominantly in the US market. These factors are summarized in Table 23.

Figure 22 Proximity Value for Automotive Production and Product Engineering

	Production **(Manufacturing Engineering)**	**R&D** **(Product Engineering)**
OEMs close to customer/market (value of proximity)	Lower transport costs Lower trade barriers (trade policy) Increased political/ reputation gain Lower currency risk	Localization function Engineering regional-specific vehicles
Suppliers close to OEMs (components with high proximity value)	Components that are bulky and relatively expensive to ship: fuel tanks Components that require sequenced just-in-time delivery to assembly plant: seat sets Components that require careful production coordination with assembly plant: bumpers (which require careful color matching with assembly plant paint shop)	Components that are highly integral to the vehicle architecture

Suppliers have many powerful incentives to locate their production facilities close to their OEM customers. The International Motor Vehicle Program interviewed many industry managers as part of its Lean Location Logic project. The goal of the project was to assess how suppliers make location decisions. While the primary focus of the study was on production location decisions – where to build or expand manufacturing plants – much insight was also gained into the engineering and design process. During these interviews, it became clear that suppliers have powerful incentives to follow their OEM customers. Lean flow, one of the underlying principles of lean production, provides a bias for proximity of suppliers to vehicle manufacturers, especially to increase customer responsiveness for lower-volume, more flexible assembly plants.[16]

[16] For more on lean flow, see Womack, James and Daniel Jones, *Lean Thinking*.

There are certain types of components that make more sense to source close to the vehicle assembly plant. Components that are bulky don't make much sense to source from distant locations due to the high transport costs. Fuel tanks and built up exhaust systems are examples of such components. Components that need to be delivered to the assembly plant in a precise sequence should also be sourced locally. Seat sets – the combination of driver, passenger and rear seats supplied for a particular vehicle – are an example of a complex sequencing operation for a vehicle assembly plant. Seat factories are almost always located close to the final assembly plant. The seat suppliers receive the build sequence – the particular vehicles that will be built within a given time period – usually with only a few hours of notice. The seat sets are loaded into trucks and delivered to the assembly plant just-in-time for installation to the vehicle. Bumpers, side mirrors, door cladding and other components that require a precise color match should also be located close to the vehicle final assembly plant. The factors are summarized in Figure 22.

We have witnessed the phenomenon of OEMs pulling their suppliers to new assembly plant locations with the *insourcing* of foreign manufacturers to the United States. When Hyundai invested over $1 billion to build a new assembly plant in Montgomery, Alabama, in 2005, it also brought in several of its suppliers. Some of these suppliers were among Hyundai's traditional supply base, such as the large Mobis plant just down the road from the Hyundai assembly plant. The Mobis plant produces front end modules, chassis modules, cockpit modules – essentially large, built up chunks of the vehicles – and supplies them to the Hyundai assembly plant. Hyundai also attracted US suppliers to its new assembly plant in Alabama. Lear, a tier one American supplier, built what the company considers to be its state-of-the-art seating factory to supply seat sets exclusively for the Hyundai assembly plant located just minutes away by truck.

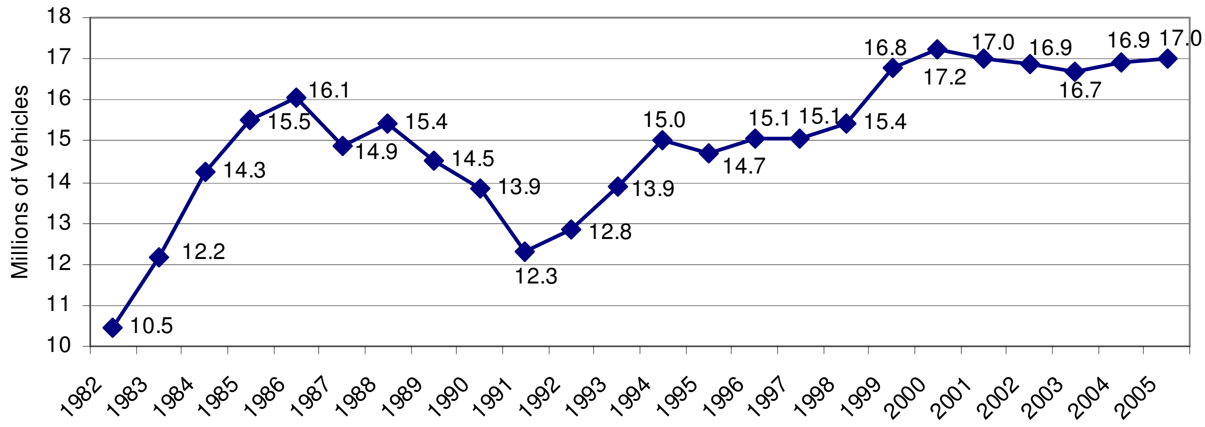
There are also certain components that make sense to engineer close to the vehicle engineering center, that is, where there is a benefit to the supplier engineers being close to their OEM engineer counterparts. In general, for components that are highly integral to the vehicle architecture, there is a benefit to the supplier engineers being located close the OEM vehicle engineering team for the particular vehicle under development. Key supplier engineers are often collocated at the vehicle manufacturer as part of a vehicle development program. As problems and concerns arise during the vehicle development process, proximity facilitates interaction, iteration and, therefore, faster resolution of the issue at hand.

The key point of Figure 22 is that proximity does have value in the automotive industry – the automotive world is not entirely flat. Customers pull vehicle production, and to a lesser degree vehicle engineering, closer to the end market. Suppliers follow their OEM customers for production and engineering of certain components. Finally, the global footprint of customers is also changing, as described in the next section.

3C-G Customer Factor: Assessing Market Growth Opportunities

The first and perhaps most important factor that influences the footprint of product and manufacturing automotive engineers is the location of the customer. The US automotive market, like the Western European and Japanese markets, is a mature, replacement market – vehicle sales have been flat for nearly seven years and are projected to remain relatively flat over the next decade. Figure 23 shows that US sales of light vehicles (passenger cars and light trucks) have been high (roughly 17 million units) but flat since 1999. Although the industry has historically demonstrated cyclical behavior, most analysts expect the US market to remain relatively flat over the next five years, hovering between 16.5 and 17.5 million units through 2010.

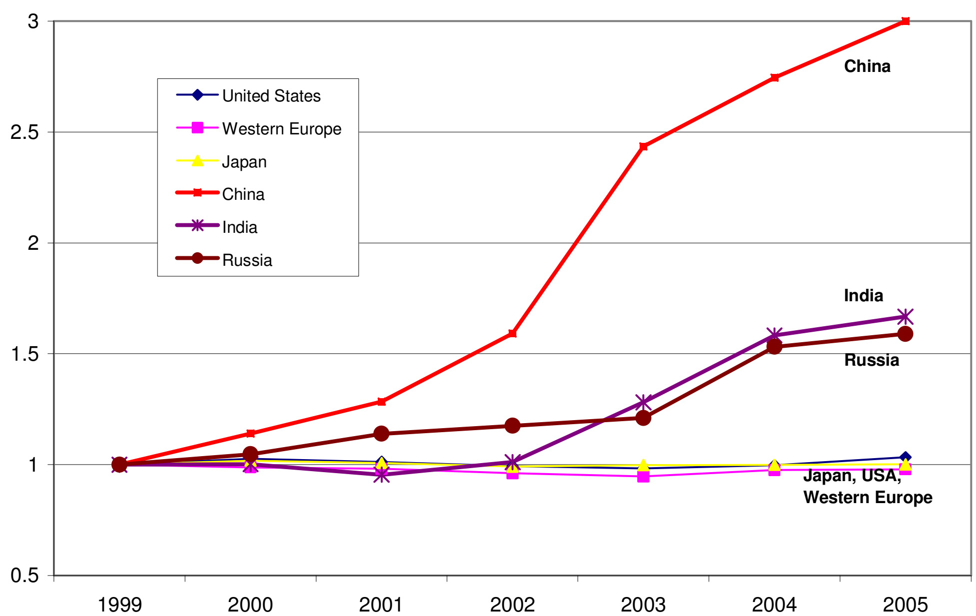
Figure 23 US Light Vehicle Sales 1982-2005



Source: Automotive News, Wards

Despite stagnant vehicle sales in the developed markets, global vehicle sales have consistently grown, increasing approximately 13% between 2001 and 2005. Industry sales totaled 64.7 million vehicles in 2005, representing a 3.7% increase over 2004. Almost all of this growth is attributable to key emerging markets, particularly China, India, Brazil and Russia. Figure 24 shows vehicle sales normalized to 1999 volumes in the three developed markets of USA, Western Europe and Japan and the three developing markets of China, India and Russia.

Figure 24 Vehicles Sales Growth Rates in Key Markets



Source: Automotive News data

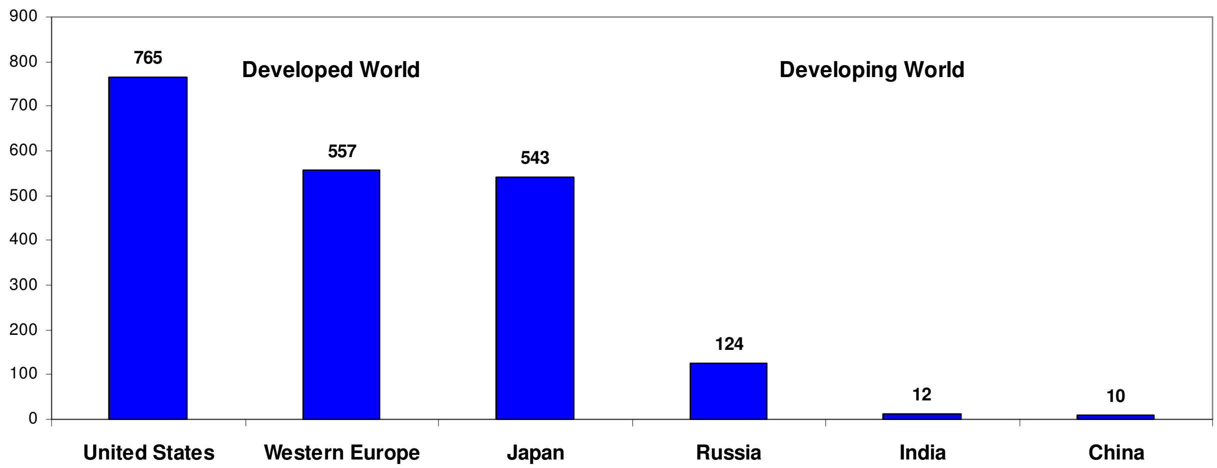
Vehicle sales growth is primarily driven by two factors: vehicle saturation rates and income growth. Vehicle sales growth has occurred and will continue in developing countries, particularly China and India, as shown in Table 10. Figure 25 shows that the developed markets are saturated in terms of vehicle ownership rates, but there is ample opportunity for motorization in the developing world.

Table 10: Vehicle Sales (000) in Key Developed and Developing Markets: 1999-2004 and Growth Rate over 5 Years

Country or Region	1999	2000	2001	2002	2003	2004	Vehicle Sales Growth (%): 1999-2004	Average GDP Growth (%): 1999-2004
United States	16,959	17,402	17,178	16,848	16,676	16,913	-0.3	2.78
Western Europe	17,269	17,053	16,944	16,608	16,352	16,856	-2.4	1.97
Japan	5,861	5,964	5,907	5,813	5,849	5,853	-0.1	1.66
China	1,832	2,089	2,353	2,917	4,461	5,230	185.5	8.52
India	857	859	818	867	1,098	1,298	51.5	5.74
Russia	1,102	1,154	1,256	1,295	1,334	1,654	50.1	6.87

Source: IMVP, Automotive News Data, World Bank Development Indicators

Figure 25 Vehicles Per 1000 People: Selected Countries / Regions

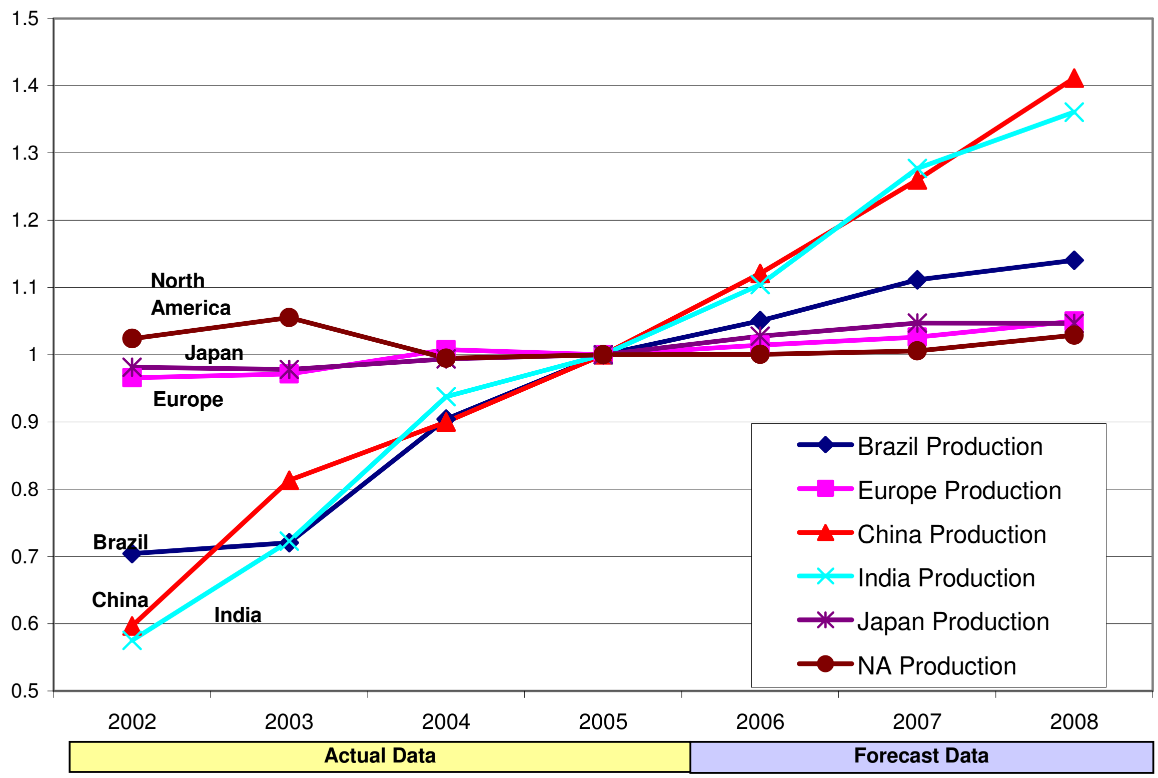


Source: United Nations Statistical Yearbook, 2000

Market growth has driven investment in new production facilities (and therefore growth in manufacturing engineers). As shown in Table 10, Chinese vehicle sales exploded in 2002 and 2003 propelling China as the #3 vehicle market (behind the United States and Japan). The promise of growth in China has attracted the attention of the world's automakers over the past decade. According to Automotive News, roughly $6 billion in automotive foreign direct investment (FDI) flowed into China between 1994 and December 2002. That same amount, $6 billion, flowed in during the following 18 months. GM has invested heavily in China since the mid-1990's. In 2005, GM surpassed Volkswagen as the Chinese market leader with sales of 665,000 vehicles (a 35% increase over 2004). China is discussed thoroughly in the next chapter.

In general, production growth has followed market growth. Figure 26 shows actual vehicle production data for the same regions shown in Figure 24. The number of vehicles produced in China and India has grown with the number of vehicles sold in China and India. While Ford and GM are in the midst of significant capacity reductions in their home market, both companies – like the rest of the world's automakers – have vigorously pursued growth opportunities in the developing world. Beyond their production facilities in Western Europe, Ford and GM have been active investors in Latin America and Mexico during the 1980's-1990's and Eastern Europe and Asia more recently. In the Asia Pacific region, GM now employs over 20,000 people at assembly and manufacturing facilities in China, India, Indonesia, South Korea, Thailand and Australia. Ford has opened plants over the past ten years in St. Petersburg, Russia; Chennai, India; and Chongqing, China.

Figure 26 Vehicle Production by Country/Region Normalized to 2005



Source: Production data from Automotive News; Forecast data from JD Power

3C-G Cost Factor: Assessing Labor Rates and Total System Costs

The desire to reduce costs is a critical driver of location decisions for both manufacturing engineers (production facility locations) and product engineers (R&D locations). All automotive companies, both OEMs and suppliers, both profitable and unprofitable, are under tremendous pressure to reduce costs. Shifting production to low cost countries (LCCs) is an acceptable strategy for many automotive managers, although there are some important caveats associated with this strategy.

One of the key findings from the IMVP Lean Location Logic project interviews is that suppliers frequently underestimate the cost to ramp up production in a low cost country. Ramping up a new production facility in a low cost country requires training (i.e., developing key capabilities) in the new workforce so that they can achieve quality and productivity levels comparable to the sister plant in the developed market. In practice, this often requires teams of production engineers and equipment technicians making extended trips to the new plant to train the workers. Several managers noted that production ramp ups took longer (resulting in delayed orders for their customers at cost to the supplier) and required more resources to train the new workforce than expected.

The automotive supply chain for most components is highly integrated; production of a given component does not take place in a vacuum. Any given component is part of an elaborate supply chain. To supply something as simple as a hydraulic pump, tier two suppliers are required to supply raw materials, fasteners, cast or forged components (such as the pump vanes), roller bearings, etc. The quality of the pump is dependent on the quality and responsiveness of the local supply base for all those sub-components. The best plant in the world located with an inadequate supply base will produce inadequate products. China, up until very recently, was *not* a low cost producer of automobiles because of the highly inefficient and costly tier two and three supply base. Beyond the requirement that local suppliers can produce components at the requisite quality, they must also be able to deliver those components – usually with just-in-time requirements. Therefore, the capability of the local supply base is also a function of the local transportation infrastructure and the capability of local logistics providers.

The highly integrated automotive supply chain is important because too often managers analyze costs based on easily quantifiable metrics, such as local manufacturing wage rates, and fail to take into account broader system-level costs. The differences in manufacturing wages across different countries are striking and well-documented.[17] Automotive manufacturing wages in Germany are around $26 per hour (unloaded), versus about $2 per hour in China. The temptation to shift manufacturing of the above hydraulic pump to a low cost country can be compelling if the local manufacturing wage rate is one tenth that of the home country. However, experience has shown that this significant advantage in the hourly manufacturing wage rate can be eliminated by lower labor productivity in the low cost country, higher production training and ramp up costs than anticipated, and higher cost to supply quality materials and parts to build the hydraulic pump.

> We've learned that chasing [ever lower] labor rates is not a sustainable business strategy. We invested heavily to build up production volumes in Mexico, only to discover that it was difficult to retain workers after investing in their training. We also discovered unanticipated costs much higher than we expected – such as the cost of customs and border clearance processes for our supply flows along the US-Mexico border.
>
> -- Chief Executive Officer, North American Tier-One Automotive Supplier

For reasons described earlier, the general mantra in the automotive industry is "build where you sell." In each of the three traditional automotive production regions of the world (the United States, Western Europe and Japan), low cost countries have emerged that are in the backyard of the production center, as shown in Table 12. For Western Europe and the United States, we have witnessed both an increase in production in these low cost countries and a significant share of that production exported back to the traditional high cost production country. In Japan, we have witnessed increased production in regional low cost countries without an increase in exports from those LCCs back to Japan. (Even today, almost all the vehicles sold in Japan are produced in Japan.)

When the North American Free Trade Agreeement (NAFTA), which lowered or eliminated trade barriers among the US, Canada and Mexico, went into effect in January 1994, Mexico emerged as a low cost country for automotive production in the backyard of the US market. Canada and the United States had strong trade in vehicles and vehicle components for years, and Canada had traditionally been a lower cost base in which to manufacturer.[18] Both Canada and Mexico

[17] See International Labour Organization, *Key Indicators of the Labor Market*, 2005.

[18] The Canadian cost advantage has declined, but automotive production in Canada is still estimated at 5.1% cost advantage for auto parts production compared to the United States, according to the 2006 edition of *Competitive Alternatives: AT Kearney's Guide to International Business Costs*. The US Corporate Average Fuel Economy (CAFE) requirements also provided incentives for US automakers to locate certain vehicle production in Canada.

currently export more than half their vehicle production volumes to the United States. The United Stated imports more passenger vehicles from Canada than from Japan. Each of the Detroit 3 manufacturers have four production facilities in Canada and Mexico combined, as shown in Table 2. Out of a total of $124.1 billion in imported passenger vehicles to the United States in 2005, the top origin countries for the imports were: $36.6 billion from Canada, $35.2 billion from Japan, $20.4 billion from Germany, $10.8 billion from Mexico, and $8.8 billion from South Korea.[19] The volume of US imported vehicles from Mexico, which provides the clearest cost advantage, has been steadily declining from $15.8 billion in 2000 to $10.8 billion in 2005. This is partially attributable to the fact that the Detroit 3 plants in Mexico produce more trucks than cars, and truck sales have suffered over the past few years due to rising gasoline prices.[20] Production losses in Mexico have been offset by production gains in Canada, as shown in Table 12.

The production footprint has also been expanding in Central and Eastern Europe with production volumes increasing 31.4% between 2001 and 2005. Since May 2004 when Poland, Hungary, Slovenia, Slovakia and the Czech Republic joined the European Union, trade barriers among the EU-15 and the new entrants were also reduced or eliminated. Poland, Hungary, Slovakia and the Czech Republic have all offered substantial fiscal incentives to attract automotive investment. In addition to the much lower labor costs, each of these countries is accessible to the automotive supply chains of Germany and Austria and therefore can provide a local low cost production center for Western Europe. Each of these countries has been both increasing automotive production and increasing exports to Western European countries, as show in Table 11.

> Within the radius of a one hour flight in Europe, manufacturing wages range from €5 to €50. We [car companies] cannot ignore that; we are not in a position to negotiate with our customers.
>
> -- Chief Executive Officer, European Vehicle Manufacturer

Table 11 Local Low Cost Countries for Key Automotive Production Regions

Triad Region	Low Cost Countries	2001 Production in LCCs (000s)	2005 Production in LCCs (000s)	Percent Change
USA	Canada, Mexico	4,396.5	4,390.3	-0.1%
Western Europe (Germany, France, UK, Italy, Belgium, Spain)	Czech Republic, Poland, Slovakia, Slovenia, Hungary, Romania	1,341.1	1,762.6	+31.4%
Japan	Thailand, Malaysia, Indonesia, Philippines	1,248.9	2,270.2	+81.8%

Data Source: Automotive News
Notes: Production declined 9.1% in Mexico and increased 6.4% in Canada.

Japanese manufacturers have been increasing production in the Asian low cost countries of Thailand, Indonesia, Malaysia and Viet Nam. Despite the increase in production volumes in these countries, the Japanese OEMs have not exported vehicles produced in these countries to the Japanese market. Imports to Japan of Japanese-brand vehicles have actually declined from 90,682 in 1995 to 19,119 in 2005 – both irrelevant compared to the overall Japanese market of

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19 Data from International Trade Administration, US Dept. of Commerce. Data are for Harmonized Tariff Schedule of the United States code 8703 "Motor cars and vehicles for transporting persons". See http://tse.export.gov/

20 See Business Week, June 13, 2005, *Mexico's Carmakers in a Ditch*.

roughly 5.9 million units in 2005.[21] Instead, the Japanese OEMs have used Thailand and other Asian LCCs to increase their vehicle production to the home markets of those markets and the Asia Pacific region in general.

There are start up costs associated with teaching local manufacturing engineers at an offshore plant the basic production principles and procedures followed by each company. Toyota, for example, is well known for its Toyota Production System, which strives to create value and eliminate waste from the production process through principles such as just-in-time (smooth flow, minimize inventory), *jidoka* (build quality in, error-proof processes), *heijunka* (stabilize production schedule variability) and *keizan* (continuous improvement). When Toyota opens new assembly plants in places as varied as Kentucky, Thailand, Turkey and France, a key challenge is to ensure that the business culture of the Toyota Production System is understood and embraced at the new facility. Toyota chooses to keep production of its high-end vehicles (e.g., Lexus) in Japan, and many other OEMs follow a similar strategy.

Fully assembled motor vehicles follow the "build where you sell" mantra, or, as we have seen above, "build close to where you sell." For automotive components, the story is a bit more complex. As discussed previously, certain components make more sense to be sourced close to the OEM assembly plant, such as bulky or sequenced components. Some automotive components are more easily sourced to a low cost country. Automotive components that are highly labor intensive and still easily transportable make sense to shift to an LCC. Wire harnesses are a good example of a highly labor intensive product. Wire harnesses, which connect all the electrical functions of a vehicle, are built up from thousands of strands of individual wire that are braided into a complex product with many branches and end connectors. The work is highly labor intensive and does not easily lend itself to automation. Wire harnesses are an early candidate for a component to shift to a LCC. On the other hand, highly capital intensive products, such as a nozzle for a diesel fuel injector, may not at all be suitable for production in a low cost country. Diesel fuel injectors are highly sophisticated products that require a clean-room production environment and sophisticated production equipment. The lower labor cost advantage is decreased due to the relatively low labor content of the product. Further, some sophisticated components require manufacturing knowledge that is not easily transferred to a new production location.

All of the cost factors discussed above pertain to offshoring production of full vehicles or vehicle components, which can be used as a long-term proxy for the manufacturing engineering footprint. The offshoring of the product design function is also driven in part by cost considerations. All of the industry managers interviewed were asked to provide an estimate of the cost to the company to employ a product engineer with 5-10 years experience in six different countries/regions. The answers varied widely both within and among regions, as shown in Figure 27. A "fully-loaded" experienced engineer in the United States may cost $100,000, while an equivalent engineer in China may cost $15,000.

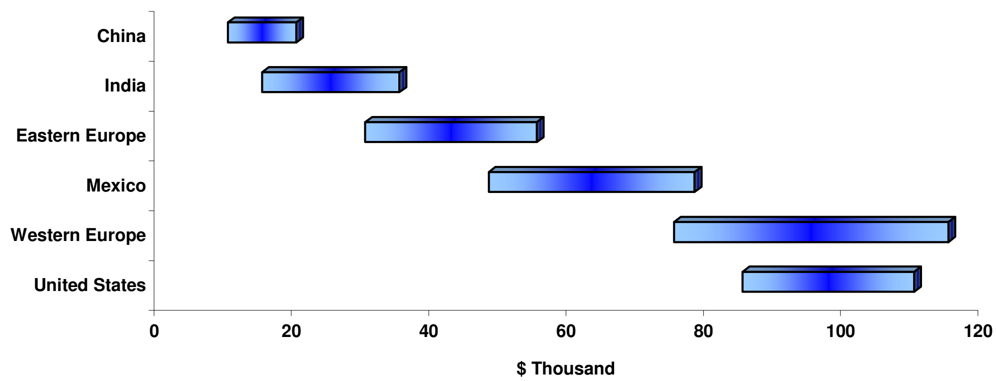
Just as manufacturing labor costs should not be viewed as the primary determinant for production facility location decisions, engineering labor costs should not be viewed as the primary determinant for where to locate the product design function. The following factors should also be considered:

- Chasing low labor rates does not provide sustainable advantage. Just as with manufacturing, engineering labor rates can increase over time.

[21] See Japan Automobile Manufacturers Association, *The Motor Industry of Japan 2006.*

- Engineering labor accounts for roughly one third to one half the full cost of engineering for the vehicle development process.[22] Other major costs include: the cost of vehicle prototypes, testing equipment and laboratories, buildings/office space, software licenses, etc. Engineering software licenses for products like CATIA are very expensive regardless of location of usage. As of June 2005, a CATIA license cost roughly $5000 per user, regardless of the geographic location of the user.
- Low productivity can make the effective cost of engineers in "low-cost" countries much greater. The same executive who estimated the annual loaded cost of an engineer in Shanghai at $10,000 per year noted that after training and adjusting for output, the cost is easily $20,000 per year. Many interviewees cited the lack of domain knowledge as the key factor in lowering labor productivity of engineers in countries like India and China.

Figure 27 Approximate Fully-Loaded Annual Automotive Engineering Labor Rates by Country/Region for an Automotive Engineer with 5-10 Years Experience



Source: Interviews with industry managers
Note: Fully-loaded was defined as total cost to the firm of employment of one FTE.

In conclusion, cost is a critical and important factor for driving location decisions, and labor costs (both manufacturing labor and engineering labor) are an important driver behind cost. There are certain vehicles or certain vehicle components that make sense to manufacture in a low cost country – and there are others that don't. There are also certain vehicles and vehicle components that make sense to engineer in a low cost country – and there are others that don't. Automakers and suppliers will use every means available to reduce their overall production and engineering costs – including shifting some production to low cost countries.

> No one has the solution to this problem. If you don't move some jobs away from your home base, you could be overwhelmed by competitors who are willing to do this. On the one hand, your family looses jobs. On the other hand, if we don't shift jobs to places like India and China, we're all dead.
>
> -- Chief Executive Officer, European Vehicle Manufacturer

3C-G Capability Factor: Assessing Regional Skills

For production of vehicles and components, capability has a low impact on production footprint strategy as shown in the 3C-G model. The capability of the local manufacturing workforce and the local manufacturing engineers is a factor in the production footprint strategy, but less of a

[22] Based on interviews and estimates by dividing overall engineering headcount multiplied by $100,000 per engineer divided by overall R&D budget.

factor than customer location, government policy and cost. On the other hand, capability has a high impact on the product design footprint strategy. If a firm is to shift a product engineering function to an offshore location, at minimum there must be qualified engineers available to perform the tasks required for that function. This in turn requires a sufficient engineering education infrastructure producing an adequate supply of qualified engineers.

Vehicle manufacturers can offshore product engineering in two ways:

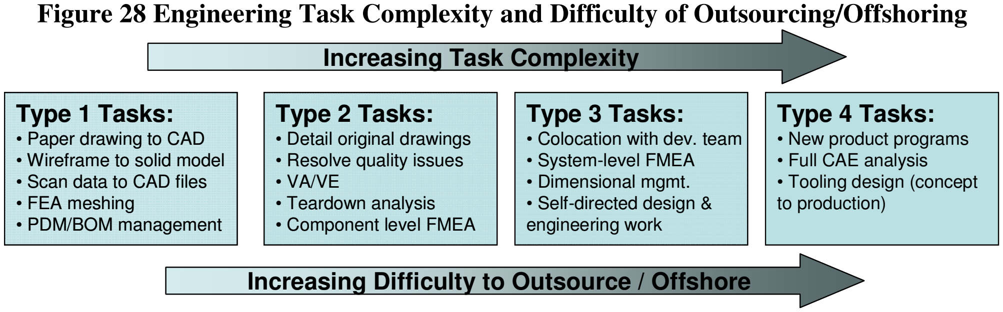
1) Offshore the full vehicle engineering program for a specific vehicle program or a family of related vehicles (e.g., large rear-wheel-drive cars).
2) Offshore part of the vehicle engineering process, such as a particular task or area of expertise.

Offshoring full vehicle programs will be discussed in the next section. With respect to offshoring certain engineering functions, several interviewees noted that the low-cost countries are better suited for certain types of engineering work. Among tasks and functions most frequently cited were:

- Repetitive or routine tasks that require technical skills but not innovative creativity. Examples include documenting an engineering bill of materials, performing a failure modes effects analysis (FMEA) process, certain type of routine stress analysis or heat transfer calculations, and generating a tool design from a part specification.
- Specialized functions that leverage local expertise or capability. Vehicle manufacturers can use offshore R&D centers as a center for excellence in a particular technology or capability, such as computational fluid dynamics.
- Localization tasks: the process of taking a vehicle (or component) designed in one part of the world and modifying it to comply with local regulation or customer preference in a different part of the world.

A study by Booz Allen Hamilton also concluded that higher value-added automotive engineering tasks are more difficult to offshore. Routine tasks that are relatively low-skilled, such as creating a mesh for a finite element model, are the easiest to outsource or offshore. Other more demanding tasks, such as the full engineering responsibility for a vehicle program, are more difficult to outsource or offshore. Almost all the interviewees for this report agreed that more complex engineering tasks were more difficult to offshore, although there was some disagreement as to the degree of complexity for various tasks.

Figure 28 Engineering Task Complexity and Difficulty of Outsourcing/Offshoring



Source: Bill Jackson, Vikas Sehgal, Kevin Dehoff and Vinay Couto. *Engineering Offshoring in the Automotive Industry*. Booz Allen Hamilton.
Notes: CAD = Computer Aided Design, FEA = Finite Element Analysis, FMEA = Failure Mode Effects Analysis, VA/VE = Value Analysis / Value Engineering, CAE = Computer Aided Engineering

I don't use my engineers in China for innovation. The culture is imitative, not innovative. They are great for reverse engineering, and so we use Chinese engineers for many of our aftermarket applications.

-- Asia-Pacific Managing Director, North American Tier-One Automotive Supplier

There were two other overarching messages to emerge from interviews of automotive executives in the United States. First, many managers expressed concerns about the lack of automotive domain knowledge among engineers in low cost countries. Some automotive engineers in China have not even driven a car, much less owned a car, so they lack a basic familiarity with the product.

When hiring engineers, we need two things. We need the basic skill base – mathematics and technical aptitude – and we need automotive domain knowledge. We hired a lot of people to staff up [oversees R&D center] and we discovered a lot of them didn't know much about how to engineer cars.

-- Top R&D Executive, US Vehicle Manufacturer

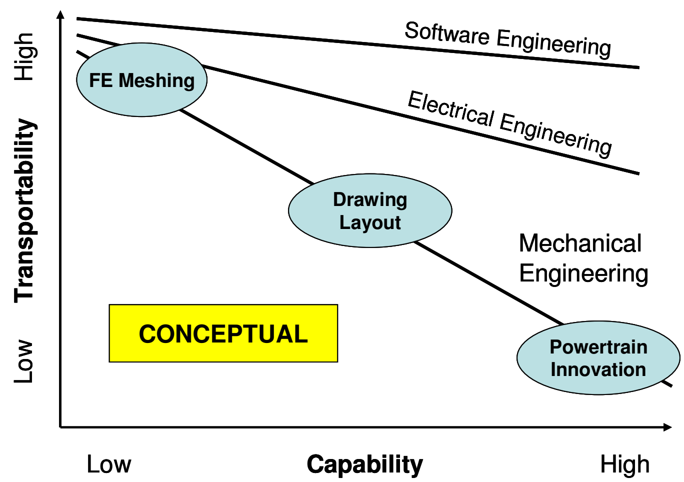
A second concern expressed by some automotive managers is that there is a shortage of engineers in the United States, particularly engineers with certain skills.

In Mexico, an engineer costs ten times a manufacturing employee. In the United States, an engineer costs about the same as a manufacturing employee. Think about that. The issue is not cost; the issue is supply [of capable engineers]. We have a big problem with engineering in this country: it's called "where's the talent?" My view [for my firm's engineering footprint] is that growth will occur oversees and engineering in the US will remain flat.

-- Chief Executive Officer, US Tier One Supplier

The value of electronics content in the automobile has been steadily rising during the past two decades. The electronics and software content of vehicles relies more on electrical and software engineers than on the traditional mechanical engineers associated with the automotive industry. Several of the interviewees indicated that electronics and software engineering functions are easier to outsource or offshore than mechanical engineering functions. Software engineers across an ocean can discuss a few lines of code easier than mechanical engineers can discuss how to modify the design of a component. Software and electronic systems also tend to follow a more modular product architecture than mechanical systems; therefore, it is easier to offshore both low and high value added functions. Figure 29 shows a conceptual model of transportability (i.e., ability to offshore) versus capability of tasks for mechanical engineering versus electrical and software engineering.

Figure 29 Conceptual Model of Capability versus Transportability Trade-Off in Various Engineering Disciplines



Globalization of Automotive Engineering: Improving Coordination of Global R&D

Engineering managers at Ford, GM and DaimlerChrysler report that their top priority is developing better coordination among their existing engineering functions around the world, rather than offshoring engineering from the United States to other parts of the world. Despite many previous attempts to increase global coordination, at the beginning of this decade Ford, GM and DaimlerChrysler each had several regional engineering centers primarily supporting the respective regional markets. The product planning function – the critical process of deciding which vehicles will be brought to market and at what level of funding – was also relatively decentralized, with regional executives exercising relative autonomy over headquarters. GM Vice Chairman Robert Lutz joked in 2004 that "up until a few months ago, GM's global product plan used to be four regional plans stapled together."[23] Ford and GM (and Volkswagen) followed a *multinational* business model: distributed and (mostly) independent regional R&D centers supporting mostly autonomous regional operations.[24]

The highly decentralized and independent nature of GM and Ford's global network of R&D centers was largely a result of their history. Ford and GM both developed significant European operations during the 20th century, each selling distinct European vehicles engineered by European engineers built in Europe by European workers with parts supplied by European suppliers. Ford's Engineering Centers near Cologne, Germany and in England supported Ford of Europe. GM's European engineering centers were aligned by brand: for example, Rüsselsheim, Germany supported Opel and Millbrook, UK supported Vauxhall. Ford and GM's acquisition of European brands during the 1980's and 1990's further complicated the picture. For example, Ford acquired Volvo's engineering center in Gothenberg, Sweden, when the company purchased Volvo in 1999, and GM acquired the Trollhättan, Sweden, facility with their purchase of Saab.

Ford and GM are now focused on integrating their regional engineering centers so that engineers across the globe coordinate on global programs. The objective is not to engineer the

[23] Hawkins, Lee Jr. *Reversing 80 Years of History, GM Is Reining in Global Feifs*. Wall Street Journal, October 6, 2004.

[24] Although Ford and GM conducted vehicle development in Europe for their European vehicle lines, both firms conducted the majority of their basic and applied research in the United States through the 1990's.

same vehicle for different markets, which is known as the “world car” vision. Rather, the objective is to engineer a family of vehicles with the same underlying structure that can very easily be modified to meet local customer and (environmental and safety) regulatory requirements. Achieving this objective requires greater centralization of the product planning function and greater coordination among the global network of product development centers. Both GM and Ford have targeted this new *transnational* business model that entails better coordination among each company’s network of R&D centers.

GM transitioned from brand-specific engineering to regional engineering, and is now transitioning from regional engineering to global engineering. GM headquarters declined requests from, for example, its Daewoo subsidiary to build an SUV for the Korean market rather than leverage an existing GM vehicle program already under development. GM uses the term *architecture* to describe a family of vehicles that may appear very different to the customer but have some basic engineering commonality. For example, the Chevrolet Malibu, the Saab 9-3 and the Opel Vectra are all products of GM’s *midsize vehicle architecture*, even though these vehicles appear very different to the customer. The midsize vehicle architecture is engineered at GM’s Rüsselsheim engineering center. GM is striving to reduce the number of vehicle architectures while ensuring that the right engineers among GM’s 13 global engineering centers are employed to support each vehicle architecture. Table 14 shows which engineering centers have lead responsibility for each of the current vehicle architectures.

The Quest for the World Car

The quest for the world car has been elusive. Several times the industry has sought and failed to produce a vehicle that could be sold in markets around the world with minor modifications. Ford tried to engineer the Escort of the early 1980’s as a world car, but at launch the American version and European version had little in common. The Ford CDW27 vehicle program of the early 1990’s (which produced the Ford Mondeo, Contour and Mystique vehicles) cost over $5 billion (including new engines and transmissions) and took an agonizing seven years to bring to market. (The W stood for “World” program.) The tremendous expense of the CDW27 program was one of the driving forces behind the creation of the Ford 2000 program announced in 1994, which sought to essentially merge Ford’s European and North American vehicle development functions – a highly ambitious reorganization.

Part of the great challenge of a successful world car program is the reality that markets around the world are different. Americans have a preference for light trucks and larger vehicles, and comfort-enhancing features ranging from cupholders to video displays for the children. Europeans prefer smaller vehicles with better vehicle dynamics (ride and handling) characteristics. Europeans have also embraced the diesel engine, with nearly half the vehicles sold across Europe with a diesel engine.[1] Many Japanese consumers prefer on-board information features such as navigation systems and purchase minicars – a segment unknown in the United States and still rare in Europe. Minicars are remarkably small vehicles (less than 11 ft. long and less than 5 ft. wide by Japanese law) powered by engines typically in the range of 60hp. Led by Suzuki, minicars accounted for 35% of new car sales in Japan for January –October 2006, compared with 24% a decade ago.

Table 12 General Motors Vehicle Architectures and Respective Home Engineering Centers

Architecture (vehicle family)	Home Engineering Center
Luxury RWD Car	Warren, MI USA
Compact Crossover	Warren, MI USA
Performance Car	Warren, MI USA
Full-Size Truck	Warren, MI USA
Mid-Size Truck (regional)	Warren, MI USA
FWD Truck	Warren, MI USA
Vans / Commercial Truck	Warren, MI USA

Architecture (vehicle family)	Home Engineering Center
International Mid-Size Truck	São Paolo, Brazil
Compact Car	Rüsselsheim, Germany
Mid-Size Car	Rüsselsheim, Germany
Small Car	Seoul, South Korea
Mini Car	Seoul, South Korea
RWD Car	Melbourne, Australia

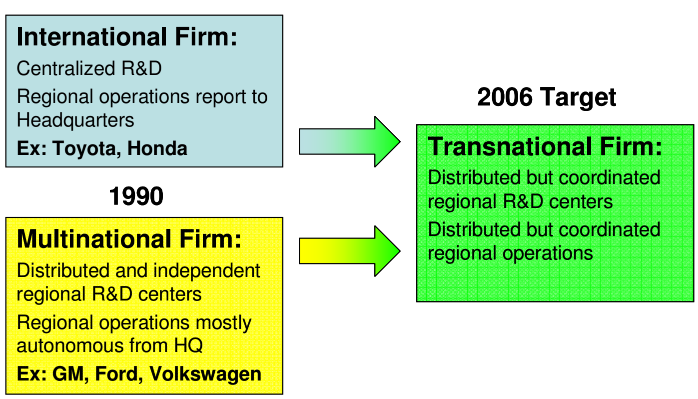
Source: General Motors

Toyota and Honda are also shifting toward a transnational business model, but from a much different starting point than Ford and GM. Toyota Motor was established in 1937 and for the first two decades sold almost all its vehicles to the Japanese home market. Toyota established Toyota Motor Sales USA in 1957, opened the Toyota Technical Center in Ann Arbor in 1977, began production in the United States (at the NUMMI joint venture with GM) in 1984, and began production in Europe in 1992 (in the United Kingdom). Despite the fact that Toyota has operated the Ann Arbor technical center for nearly 30 years, it is only quite recently that the engineers in that facility have been given deeper program-level responsibility. Toyota has a total of about 20,000 engineers in Japan; however, nearly 40% are contract employees or "guest engineers" from suppliers. Toyota – like many Japanese firms – is about to face a shortage of engineers in Japan as the first of the Japanese baby boom generation reaches the mandatory retirement age of 60, resulting in so-called *year 2007 problem*.[25] In this sense, Toyota has been forced to look outward (i.e., beyond Japan) to hire engineering talent, and this is one of the reasons that Toyota plans to dramatically expand employment at the Ann Arbor center over the next few years.

Honda Motor followed a similar evolution as Toyota, although Honda shifted greater engineering responsibility to America sooner than Toyota did. Honda was founded in 1948 and opened American Honda Motor as a sales operation in 1959. Production of the Honda accord began in Ohio in 1982, and Honda R&D Americas center in Ohio was soon established in 1984. (The Ohio facility concentrates on product engineering, development and testing; the California facility concentrates on market research and vehicle styling design.) Honda R&D Americas has full vehicle engineering responsibility for the Acura TL and MDX, and the Honda Element, Pilot and Civic Coupe.

Both Toyota and Honda started out following an *international* business model: strongly centralized R&D (very little R&D outside the home country) and regional operations with strong reporting lines to the home country headquarters. Ford, GM, Toyota and Honda are all migrating to the *transnational* business model. For Ford and GM, this means increasing coordination within an existing international network of R&D centers. For Toyota and Honda, this means striving first to shift more of the R&D function to new or existing R&D centers outside Japan, and second ensuring coordination among that international network of R&D centers. Figure 30 illustrates how these two groups of companies started with very different business models and are migrating toward the same model.

Figure 30 Evolution from International and Multinational to the Transnational Model for Automakers



[25] Toyota has recently raises the age that its retires can work under its reemployment system from 63 to 65.

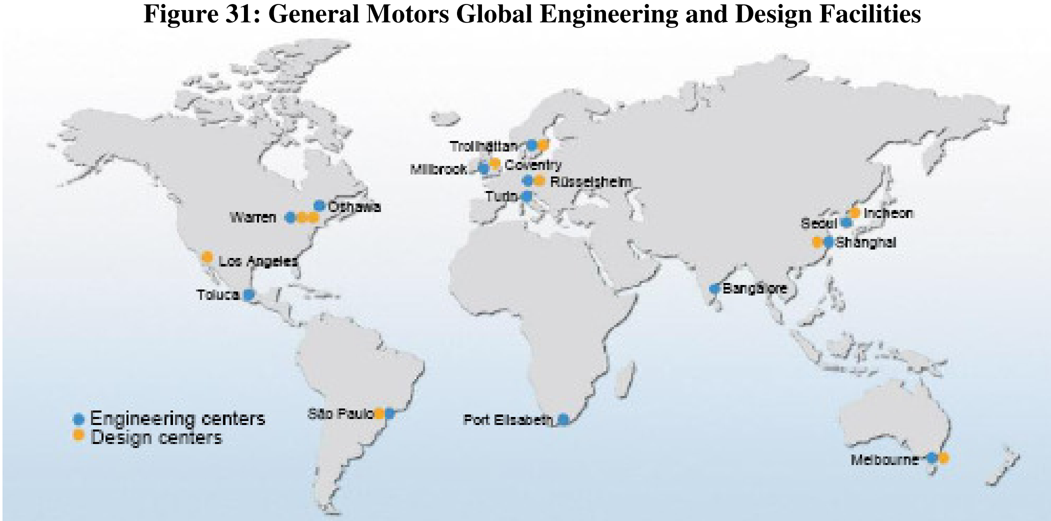
Just as the automotive industry has globalized first by brands (through imports and exports), then by production (through foreign direct investment in assembly and manufacturing plants), the latest wave of globalization includes changes in how automakers manage their global R&D operations. From the perspective of the United States, there are two sides to this story: US companies have increased their R&D footprint outside the United States, while decreasing their R&D footprint in the United States. On the other hand, foreign companies have increased their R&D footprint within the United States.

Globalization of Automotive R&D: Domestic Firms Increasing Foreign R&D Employment
Figure 31 shows GM's global network of engineering and design (styling) centers. GM operates 13 engineering centers in 13 different countries. While GM's has had a strong market, production and R&D presence in Europe and Latin America for decades, it has more recently entered into China (1997), South Korea (2002) and India (2003). Ford Motor Company reports that it spent $8.0 billion on engineering research and development in 2005 distributed across seven engineering, research in design centers located in: Dearborn, Michigan; Dunton, UK; Gaydon, UK; Whitley, UK; Gothenburg, Sweden; Aachen, Germany; and Merkenich, Germany.[26]

GM views its Bangalore, India, Technical Center as a center of excellence for math-based tools and automotive electronics controls systems, which includes: module and system development; human modeling for crashworthiness prediction; vehicle structures; control software; embedded systems; software validation and calibration tools; voice recognition and communications; vehicle electrical system simulation; electro-mechanical simulation. The rationale behind opening the Bangalore center was to develop a specialized engineering capability.

> Electronics and software content will account for 40% of the value-added in the vehicle over the next ten years. There's a shortage of software, electronics and control engineers in the US – that's part of why I opened our [oversees] R&D center. I think we will see a shortage of engineers in the US.
>
> -- Top R&D Executive, General Motors

Figure 31: General Motors Global Engineering and Design Facilities



Source: GM Europe

[26] Ford Motor Company Form 10-K filed 3/1/2006 for period ending 12/31/2005.

Globalization of Automotive Engineering: Foreign Firms *Onshoring* R&D

The foreign-brand automakers also built product development and design facilities in addition to manufacturing plants in the United States. Total technical and design employment of foreign-brand automakers in the United States is currently estimated at approximately 4,000 people, as shown in Table 13. (This figure does not include sales and marketing staff located in the United States, which accounts for thousands more employees.) Table 13 shows that the foreign R&D facilities are quite distributed across the United States; however, the majority of engineering talent is employed in the Michigan/Ohio area.

Table 13 Foreign-Brand Research & Development and Design Facilities in the United States

Company	Location(s)	Established	Employees
BMW	Spartanburg, NC; Woodcliff Lake, NJ; Oxnard, CA; Palo Alto, CA	1982	150
Honda	Torrance, CA; Raymond, OH	1975	1300
Hyundai *	Ann Arbor, MI	1986	150
Isuzu	Cerritos, CA; Plymouth, MI	1985	100
Mazda	Irvine, CA; Ann Arbor, MI; Flat Rock, MI	1972	100
Mercedes-Benz	Palo Alto, CA; Sacramento, CA; Portland, OR	1995	50
Mitsubishi	Ann Arbor, MI	1983	130
Nissan	Farmington Hills, MI	1983	1000
Subaru	Ann Arbor, MI; Lafayette, IN; Cypress, CA	1986	30
Toyota *	Gardena, CA; Berkeley, CA; Ann Arbor, MI; Plymouth, MI; Lexington, KY; Cambridge, MA; Wittmann, AZ;	1977	1000

Source: Japan Automobile Manufacturers Association, Automotive News, Company reports and interviews
Note: * Toyota and Hyundai are currently undergoing significant expansions. BMW included approx. 50 engineers assigned to BMW-DCX-GM hybrid project in Troy, Michigan.

Figure 32 Foreign Brand R&D Centers in the United States

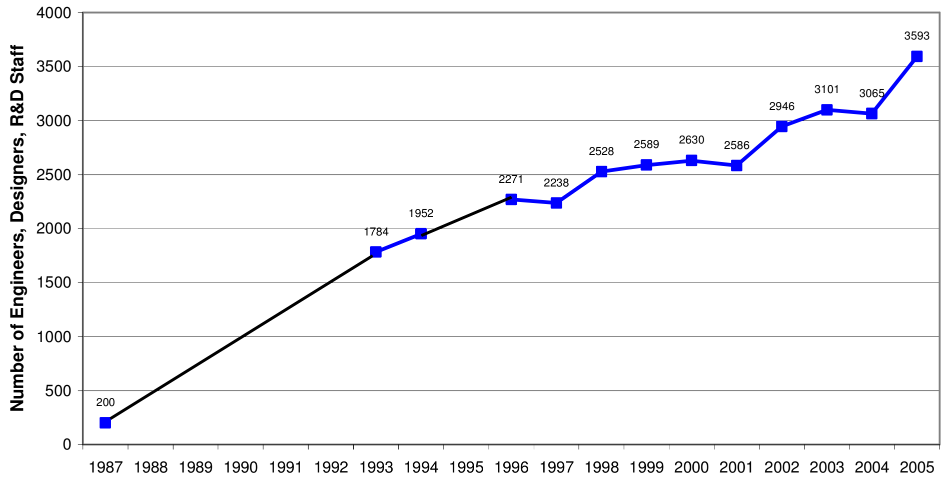
Nissan Technical Center, Farmington Hills, MI

Toyota Technical Center, Ann Arbor, MI

The current employment estimate of roughly 4,000 engineers and designers for the foreign-brand vehicle manufacturers in the United States is increasing rapidly. In 1987, the Japan Automobile Manufacturers Association (JAMA) estimated the Japanese automakers employed about 200 engineers, scientists, technicians and designers in the United States. By 2004, JAMA reported that 3,065 engineers and designers worked at the growing number of technical R&D and design facilities in the United States. Their latest report, issued in September 2006, estimates 2005 R&D employment of the Japanese automakers in the US at 3,593. The JAMA data is shown in Figure 33.

US engineering employment at the foreign automakers is expected to increase substantially over the next few years. For example, Toyota plans to invest $150 million to expand its Ann Arbor, Michigan facility and add at least 400 engineers to the current staff of roughly 950. One Toyota executive stated that Toyota plans to expand the Ann Arbor facility to 2,000 engineers over the next five years. Also in Ann Arbor, Hyundai is investing $117 million to expand its technical center from 150 to 550 employees. The Detroit metropolitan area is a cluster for automotive engineering talent. Over the past few years, scores of engineers have left the domestic OEMs to take jobs with the foreign OEMs, and this trend shows no end in sight.[27]

Figure 33 US Technical Employment at Japanese Automakers



Source: Japan Automobile Manufacturers Association

Discussion: Are Automotive Engineering Jobs Being Offshored?

Many of the industry executives emphasized that the question "is offshoring occurring?" is the wrong way to frame the issue. They are quick to point out that the industry has been global since its inception and that real question is how to optimize and reallocate existing resources – how to develop a footprint strategy.

GM acknowledges that it has increased its engineering headcount oversees and reduced its engineering headcount in the United States. However, GM contends that *offshoring*, defined as a replacement of US engineering jobs with equivalent oversees jobs, has not occurred. GM's executive director of global engineering process reports that the main driver for the increased engineering headcount oversees is to support the growth from key markets, such as China, India and Korea. He reports that the main driver for the decreased engineering employment in the United States is a 10% increase in engineering productivity per year over the past five years due to better tools and information technology, more sharing of common components among vehicles, and better coordination of the R&D function.[28]

Many of the interviewees also felt that there was a great deal of hype and misunderstanding surrounding the offshoring question.

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[27] See Shirouzu, Norihiko. Wall Street Journal. *Foreign Car Makers Grab U.S. Resource: Automotive Engineers*. Dec. 6, 2005, or Vlasic, Bill. The Detroit News. *As Best Auto Jobs Fade: Big 3 White Collar Workers Turn to Transplants and Suppliers*. June 20, 2004.

[28] Report to the National Academy of Engineering *Offshoring of Engineering* workshop, October 24, 2006, Washington, DC. John Cohoon, Executive Director, Global Engineering Process, General Motors Corp.

I laugh about the notion of 27/7 product development process – the idea that engineers in Europe will hand off a project to engineers in North America who in turn will pass it on to engineers in Asia. That's a myth. Hand-offs don't happen for sophisticated [development] programs.

-- Senior Vice President, Technology, North American Tier-One Automotive Supplier

There are data to indicate that some US engineering jobs are being replaced with engineering jobs oversees. In 2003, Helper and Stanley surveyed 615 small/medium enterprises (SMEs) making components in the US Midwest region. The sample firms were second tier suppliers that sell largely, though not exclusively, to the automotive industry. 87% of respondents answered "yes" to the question: *"In the past three years, have any of your significant customers awarded your traditional jobs to competing suppliers in Mexico, Central or South America, Eastern Europe, or Asia?"* (Yes/No).

The Growth of Automotive Engineering in China

Automotive engineering activity is clearly growing in India, China and Eastern Europe. The particular combination of underlying drivers behind the growth is different in each of these three regions. India is viewed as an emerging knowledge hub in automotive electronics. Eastern Europe is viewed as a low-cost, technically-advanced workforce. Renault announced in October 2006 that it will invest €500 million for a new engineering center in southern Romania. Renault will hire 1600 engineers and technicians by 2009.

The Rise of the Chinese Auto Industry

As recently as 1985, the Chinese automotive industry was completely insignificant from a global perspective (total passenger car production of 5,200). During the early 1980's, three foreign automakers were allowed to enter the Chinese market through joint venture agreements with Chinese partners: American Motor Corporation (subsequently bought by Chrysler), Volkswagen, and Peugeot. Volkswagen's China partnership, based in Shanghai, proved to be very successful, whereas the French and Americans were less successful. Even with these early joint ventures, the Chinese government limited foreign automakers to a maximum 50% ownership in the joint venture. Chinese import duties on passenger cars were 260% in 1985.

Following China's accession to the World Trade Organization in December 2001, the industry and market have underdone a radical transformation. The WTO agreement, combined with the lure of China's huge potential market, spurred the global automakers to flood China with investment. Each vehicle manufacturer sought a Chinese partner to form an international joint venture. Chinese import duties on passenger cars fell from roughly 90% in 1996 to roughly 75% in 2001. With the WTO agreement, China's duties were reduced to 25% as of July 1, 2006.

Today, China is a huge and growing automotive market. In terms of the number of vehicles sold, China emerged last year as the 2nd largest automotive market in the world (almost 6 million units versus roughly 17 million units in the United States).[29] The Chinese market exploded in 2002 and 2003 with growth rates surpassing 60% both years. (Recall that the vehicle sales growth rate in all three mature automotive markets – the United States, Western Europe and Japan – has been essentially zero over the past five years.) After a slight slowdown around 2004, the torrid growth in the Chinese market continues: passenger car sales increased 47% for the first half of 2006 over first half 2005.

The Chinese automotive industry is uniquely fragmented and complex. The number of vehicle manufacturers in China has remained steady – about 120 – for the past fifteen years. Many of these 120 firms have insignificant volumes. In 2004, there were only 12 Chinese automakers with production capacity greater than 100,000 units. Shanghai Automotive Industry Corporation (SAIC), First Automotive Works (FAW), Dongfeng, Beijing Automobile Industrial Corporation (BAIC), are some of the leading Chinese automakers. These Chinese automakers have entered into a complex web of partnership arrangements with the foreign manufacturers. SAIC, for example, has a joint venture with both Volkswagen and General Motors. There have also been a few so-called independents – indigenous Chinese companies who are developing cars without the help of a joint venture partner: Chery, Geely, and Great Wall are a few names that come to mind.

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[29] The 2005 data were subsequently recalculated by the Chinese Association of Automotive Manufacturers (CAAM) to reveal that China had not surpassed Japan; however, China will surpass Japan in 2006 sales. See Lee, Chunli. March 28, 2006. *In China, It's the Year of the Car*. World Business.

Vehicles sold from the joint ventures account for about 80% of the Chinese market. Further, most of these joint-venture produced vehicles are sold under the foreign brands, such as Ford and Buick. In terms of geography, there are six geographic clusters of the auto industry in China: Shanghai, Beijing, Changchun, Chongqing, Wuhan and Guangzhou. There is no "Detroit" of China, although Shanghai is both the largest and fastest growing automotive center in the country.

Impact of China on US Vehicle Manufacturers and Suppliers
US vehicle manufacturers have benefited from the exploding Chinese market. Chrysler, through its acquisition of American Motors, was actually the first foreign player in China entering back in 1983. Although Beijing Jeep was not a success, DaimlerChrysler has been developing an aggressive China strategy over the past few years through its joint venture with BAIC. Ford was a late entrant to the Chinese market, partnering with ChangAn, a former supplier of military equipment based in Chongqing. At the Ford-ChangAn assembly plant in Chongqing, an impressive mix of vehicles rolls down the line: Ford Focus, Ford Mondeo, Volvo S40 and Mazda 3. Ford's first half China sales for 2006 are up 102% (while their first half US sales are down 4%). GM's strategy and progress in China have been remarkable, and GM has now emerged as the sales leader in China. GM's first half China sales for 2006 are up 47% (versus a 12% decline for US sales in the same period). GM made $327 million in profits from its China operations in 2005.[30]

All of the global tier one suppliers have also profited from China's explosive growth as they have followed their customers into China. However, many smaller tier two and tier three US auto suppliers have suffered as they have lost business to Chinese competitors. During the Lean Location Logic project, several executives told IMVP researchers that they had felt an internal pressure from senior management to view investment in China favorably, in order to achieve the benchmark of a "China price". As discussed previously, such price comparisons frequently highlight big differences in direct labor costs without accounting for broader system-wide costs.

In general, Chinese domestic suppliers are better positioned to supply low-end parts to the Chinese JVs and vehicle manufacturers, and foreign suppliers are better positioned to supply complex modules and sophisticated components. Fourin, a Japanese-based research firm that analyzes the Chinese automotive market, measured the percent of foreign (i.e., non-Chinese) penetration into the production of automotive parts in China.[31] The data for chassis-related parts are revealing. In 2003, several parts categories were manufactured entirely by Chinese firms, including wheel bolts, wheel rims, steel wheels, rear axle housings, axle shafts, etc. The common characteristic of all these parts is that they are low-end mechanical components. The three parts categories with the highest degree of foreign (non-Chinese) production were suspension systems, brake calipers and ABS systems, which are all more sophisticated components. The data for engine-related components reveal the same trend. In 2003, 100% of the engine managements systems manufactured in China were produced by foreign (non-Chinese) firms. These data focus only on automotive components produced in China, not imported components.

The US-China trade deficit in auto parts has steadily increased to $4.8 billion in 2005. US auto parts exports to China grew from $225 million in 2000 to $623 million in 2005. Some of the top categories of parts flowing from the US to China include seats, airbags and gearboxes, which

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[30] Automotive News. May 1, 2006. *2006 Guide to China's Auto Market*.
[31] Fourin China Auto Weekly. February 7, 2005. *An Analysis of China's Autopart Production: Top Manufacturers and Foreign Efforts Expand.*

are all more sophisticated components. US exports to China are dwarfed by auto parts imports from China, which grew from $1.6 billion in 2000 to $5.4 billion in 2005. Some of the top categories of auto parts flowing from China to the US include radios, brake components and aluminum wheels, which are less sophisticated and/or more modular components. (Many of the aluminum wheels are aftermarket products.) A closer look at the data show that a large proportion of this China to US auto parts trade are made by the Chinese operations or joint ventures of US suppliers, for example, Shanghai Delphi exporting automatic door systems.

Chinese R&D Capability

Up until 2004, there was only one R&D center in China related to a foreign vehicle manufacturer: the Pan Asia Technical Automotive Center (PATAC). PATAC was established in 1997 as a 50-50 joint venture between General Motors and Shanghai Automotive Industry Corporation (SAIC). The center has grown considerably and currently employs over 1100 people, about 35% of whom have masters or doctorate degrees.[32] PATAC employment should reach 1400 over the next year to support the launch of many new products from Shanghai GM, which is now approaching a production volume of one million vehicles per year.[33] PATAC is managed by an executive committee of two managers from GM and two from SAIC, but fully integrated within GM's Global Engineering Network. PATAC does product development, vehicle engineering, styling and service engineering to support GM, SAIC and Shanghai GM. PATAC also houses a GM design studio with 80 designers (out of 1200 for GM global). The center designed all new sheet metal for the Chinese edition of the Buick Lacrosse. Engineers at PATAC earn approximately $12,000 per year.

Jane Zhao, an IMVP researcher at the University of Kansas, conducted extensive interviews and survey data from Chinese automakers and suppliers focusing specifically on R&D capability. She had three key findings from her work. First, Chinese R&D capability is far behind non-Chinese competitors. Chinese vehicle manufacturers generally have a strong mechanical product development capability, but are quite weak in high-end electronics and software. As discussed, this is consistent with the foreign trade data for China.

Second, the management capability of the R&D process is less advanced in China than in other automotive producing countries. This is consistent with media reports of a shortage of management talent in certain regions and industries in China. During her interviews, the R&D manager of a well-known Chinese automotive company confessed "we don't know how to spend our R&D budget." Recently, there have been some high profile executive hires of foreign managers in Chinese automotive companies. The most notable of these is the June 18 announcement that SAIC has hired Phil Murtaugh, a talented and well-respected manager who used to run GM China. Chery has hired executives from Ford and DaimlerChrysler. Brilliance hired a

<u>Universities and Automotive R&D in China</u>

Universities in China play a unique role in the automotive R&D process. Three government-funded university labs conduct automotive applied research – essentially product engineering – for Chinese vehicle manufacturers. The centers are based at Tsinghua University in Beijing (State Key Laboratory for Automotive Safety and Energy); Tianjin University in Tianjin (State Key Laboratory for Internal Combustion Engines); and Jilin University in Changchun (State Key Laboratory for Automotive Dynamic Modeling and Simulation). Tongji University in Shanghai established the nation's first College of Automotive Engineering in 2002, where nearly 50 faculty teach 730 full-time undergraduate students, 124 masters students, and 27 PhD students.[1] Chongqing Lifan, China's top motorcycle producer, recently launched their first passenger car, the Lifan 520. The vehicle was entirely engineered at these university research labs and Chinese domestic R&D resources.

[32] See http://www.gmchina.com/english/operations/patac.htm

[33] Interview with Raymond Bierzynski, PATAC executive director, May 9, 2006.

former DaimlerChrysler executive to manage its R&D center, while Geely hired a former Hyundai executive to run its R&D operations. Given the remote locations of some Chinese automakers and, more importantly, the unique cultural requirements for success in China, it remains to be seen how successful Chinese companies will be in both attracting and retaining talented R&D managers of global caliber.

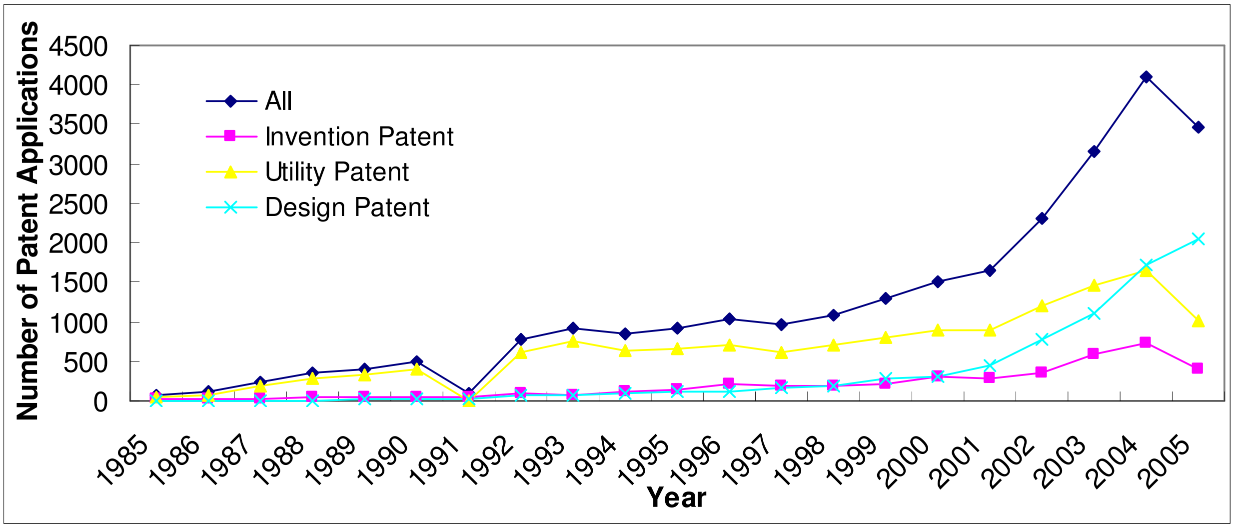
Third, a tremendous amount of R&D performed at the international joint ventures is localization. Although localization can be technically sophisticated, it is not as sophisticated as designing a full vehicle from concept to customer. Some engineers claimed that they "dumbed down" by working with the joint ventures (due to focusing more on localization and less on up-front design).

Despite the best efforts of the government to develop indigenous R&D capability, China is still heavily dependent on foreign design and technological know-how. The Chinese government's rationale for promoting international joint ventures was to develop R&D capability. One idea was that engineers from the Chinese domestic company would spend a few years working with the joint venture's R&D center where they would acquire knowledge. Eventually, the domestic company would hire back the engineer and his or her acquired knowledge. That has not happened. The backflow from the joint venture to the home company is much lower than expected due to the high salary differentials between the domestic companies and their associated joint ventures, which in some cases is a factor of ten. One also needs to consider the engineering infrastructure in terms of availability of sophisticated test equipment. China does not have an automotive wind tunnel in the entire country; the first is currently under construction and will open at Tongji University.

This is not to say that Chinese engineers within the Chinese-foreign joint venture framework haven't learned anything about advanced automotive engineering. The Shanghai municipal government has mandated that 60,000 hybrid vehicles must be sold by 2010. Chinese engineers at PATAC are working to meet the challenge. They are not leveraging the extensive research program to develop a dual-stage hybrid that GM is investing in partnership with DaimlerChrysler and BMW, but they are still engaged in advanced engineering. PATAC also boasts significant design capability. Designers – the clay modelers and CAD modelers that design the aesthetics of the vehicle (the exterior surfaces, the interiors materials and design) – require creativity and highly-specialized talent. GM employs 1200 people at their design centers around the world – and 80 are located in Shanghai. These are the people responsible for the fact that the Buick Lacrosse sold in China by Shanghai GM looks significantly different from the same vehicle sold in America. Figure 34 shows that automotive-related patent applications are on the rise in China.

Although the joint venture model for technology transfer has largely failed, there are emerging mechanisms for developing China's automotive R&D capability. Strategic outsourcing to foreign knowledge centers is now a popular model. Chery has outsourced engineering to AVL (an Austrian high-tech powertrain engineering firm), special noise and vibration testing to Mira (a British engineering and test firm) and design to Pinanfarina (an Italian design, engineering, and manufacturing house). Chery and AVL successfully collaborated on a line of new, advanced engines, and Chery gained engine technological know-how through the process. Learning is unlikely to happen from pure contractual outsourcing, but learning from collaborative outsourcing seems to be working. Another new mechanism for developing China's R&D capability is simply buying the technology from foreigners. The best example is SAIC's stakes in Korean automaker SsangYong and failed British automaker MG Rover.

Figure 34 Automotive-Related Patent Applications in China: 1985-2005



Source: State Intellectual Property Office, People's Republic of China
Note: Analysis by Jianxi Luo, PhD Candidate, MIT. Search performed for "automotive" in the title of the patent application.

There has been much debate recently over the question of whether China will export vehicles to the US market. For China to emerge as a true threat to America in the automotive domain, they will need to develop R&D capability on par with America, Germany, Japan and Korea. Achieving success in America and other key export markets is the ultimate test of an automaker's capabilities and a huge symbolic achievement, so this is definitely a high medium-term priority for the Chinese OEMs. Over the long term, there is no reason to expect that China will fail to develop automotive R&D capability and export significant volumes of vehicles to the United States. The United States has witnessed a clear pattern of increased imports followed by increased production capacity (the rise of the transplants) for Japanese, German and Korean manufacturers.

Looking Forward: Trends and Projections

Offshoring automotive engineering – as defined as a replacement of engineers in a high cost country to those in a low cost country – is one manifestation of the complex dynamics of today's global automotive industry. To focus just on the offshoring phenomenon without considering, for example, the onshoring phenomenon clearly misses the big picture. Ford and GM are closing assembly plants in North America. Toyota, Honda and Hyundai are building new plants in North America. Ford and GM are reducing engineering headcounts in the Detroit area. Toyota, Honda and Hyundai are increasing engineering headcounts in places like Ann Arbor, Michigan, and Raymond, Ohio.

Automotive engineers in the United States should be concerned about offshoring; however, there are many other issues that they should be more concerned about. Automotive engineers at the domestic vehicle manufacturers should be more concerned about the overall state of the industry and the fact that each domestic vehicle manufacturer is currently loosing billions of dollars and not earning adequate returns on invested capital. They should be concerned about the fact that many of their competitors are still more lean in product development – that is, that their competitors can bring vehicles to market faster. They should be concerned about legacy costs such as pension and retiree health benefit liabilities – that is, they should be concerned by agreements that previous managers made that are no longer tenable. They should be concerned about how their brands are cheapened when their companies run sales incentives campaigns that essentially pay customers to buy their vehicles.

One important fact should be kept in mind by all US automotive engineers: Toyota, the benchmark of the industry and the most valuable automotive company in the world, has "offshored" the least. Toyota has earned the most valuable player title by focusing on value, not by focusing on cost. If a firm uses offshoring purely as a cost cutting tool, it's unlikely to offer sustainable competitive advantage to that firm. If the firm uses offshoring (along with onshoring) as part of an integrated footprint strategy, the firm is more likely to achieve an advantage.

Asia will continue to be the driver of growth in the global automotive market. As such, it is natural to expect that the automotive production and engineering footprint in Asia will continue to expand. US engineers should continue to focus on creativity and developing cutting edge technology. Toyota is attempting to upgrade their engineers to focus on technical areas that will be the key competitive differentiators of the future. For example, Toyota has invested significantly over the past few years to increase its internal capability in software development. This is perhaps because Toyota believes that understanding the code that controls complex vehicle control systems, such as the power controllers for hybrid powertrains, is a key competitive differentiator for the future.

The global automotive industry has undergone radical changes over the past ten years, and there are no indications that the industry is stabilizing. To the contrary, the industry appears to be on the cusp of a significant restructuring. Current business models are not sustainable for many industry players. Footprint strategy will play an increasingly important role as vehicle manufacturers learn to engineer more with less.

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