Delphi IX Forecast and Analysis of the North American Automotive Industry

VOLUME 2: TECHNOLOGY

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FOREWORD

Delphi IX is a detailed analysis of forecasts by three separate panels of automotive industry executives, directors, managers, and engineers who are expert in automotive technology, materials, or marketing. These individuals were selected because they occupy positions of responsibility within the automotive industry and have strategic insight into important industry trends. In many cases, they are in a position to influence these trends. This report, published in three volumes, is ninth in a series of in-depth studies of long-range automotive trends, which began with Delphi I in 1979 and continued with Delphi II in 1981, Delphi III in 1984, Delphi IV in 1987, Delphi V in 1989, Delphi VI in 1992, Delphi VII in 1994 and Delphi VIII in 1996.

The Office for the Study of Automotive Transportation (OSAT) collects the data and analyzes, interprets, and presents the results. Since the forecasts are those of the panelists, Delphi IX is essentially the industry's own consensus forecast. These forecasts are not "crystal ball" predictions but, rather, well-informed estimates, perspectives, and opinions. Such forecasts present an important basis for business decisions and provide valuable strategic planning information for those involved in all areas of the North American automotive industry: manufacturers; service, component and materials suppliers; government; labor; public utilities; and financial institutions. We believe these to be the most authoritative and dependable North American automotive forecasts available.

A key point to keep in mind is that the Delphi forecast presents a vision of the future. It obviously is not a precise statement of the future but rather what the industry thinks the future will likely be.

As an industry-wide survey, the project also allows individual companies to benchmark their vision and strategy against consensus industry opinions.

The Delphi method: general background

The study is based on the Delphi forecasting process. This process requires that experts consider the issues under investigation and make predictions about future developments. Developed by the Rand Corporation for the U.S. Air Force in the late 1960s, Delphi is a systematic, interactive method of forecasting based on independent inputs regarding future events.

The Delphi method is dependent upon the judgment of knowledgeable experts. This is a particular strength because, in addition to quantitative factors, predictions that require policy decision are influenced by personal preferences and expectations. Delphi forecasts reflect these personal factors. The respondents whose opinions are represented in this report are often in a position to influence events and, thus, make their forecasts come true. Even if subsequent events result in a change of direction of a particular forecast, this does not negate the utility of the Delphi. This report's primary objective is to present the direction of technological, materials, and marketing developments within the industry and to analyze potential strategic importance.

Process

The Delphi method utilizes repeated rounds of questioning, including feedback of earlier-round responses, to take advantage of group input while avoiding the biasing effects possible in face-to-face panel deliberations. Some of those biasing effects are discussed in this excerpt from a 1969 Rand memorandum:

> The traditional way of pooling individual opinions is by face-to-face decisions. Numerous studies by psychologists in the past two decades have demonstrated some serious difficulties with face-to-face interaction. Among the most serious are:

(1) Influence, for example, by the person who talks the most. There is very little correlation between pressure of speech and knowledge. (2) Noise. By noise is not meant auditory level (although in some face-to-face situations this may be serious enough) but semantic noise. Much of the "communication" in a discussion group has to do with individual and group interest, not with problem solving. This kind of communication, although it may appear problem-oriented, is often irrelevant or biasing. (3) Group pressure for conformity. In experiments at Rand and elsewhere, it has turned out that, after face-to-face discussions, more often than not the group response is less accurate than a simple median of individual estimates without discussion (see N. C. Dalkey, The Delphi Opinion. Memo RM 5888 PR, p. 14, Rand Corp., 1969).

In the Delphi method, panelists respond anonymously, preventing the identification of a specific opinion with any individual or company. This anonymity also provides the comfort of confidentiality, allowing panelists to freely express their opinions. Among other advantages, this process enables respondents to revise a previous opinion after reviewing new information submitted by other panelists. All participants are encouraged to comment on their own forecasts and on the combined panel results. The information is then furnished to the panel participants in successive iterations. This procedure reduces the effects of personal agendas or biases and assists the panelists in remaining focused on the questions, issues and comments at hand.

Panel characteristics and composition

The very essence of a Delphi survey is the careful selection of expert respondents. The selection of such experts for this Delphi survey is made possible by the long-standing association between The University of Michigan's Office for the Study of Automotive Transportation and representatives of the automotive industry. Lists of prospective experts were assembled for technology, marketing and materials panels. Members were selected on the basis of the position they occupy within the automotive industry and their knowledge of the topic being surveyed. They are deeply knowledgeable and broadly experienced in the subject matter.

The names of the panel members and their replies are known only to our office and are maintained in the strictest confidence. Replies are coded to ensure anonymity. The identity of panel members is not revealed. Upon publication of the final Delphi report, all questionnaires and lists of panelists are destroyed.

The characteristics of the 266 panel members are as follows: 21 percent of the technology panel was composed of CEOs, presidents, or vice presidents; 18 percent were directors; 37 percent were executives, managers or supervisors; 16 percent were engineers (chief, assistant chief and staff); and 8 percent of the panel was made up of academic specialists and consulting technical-engineering specialists. The marketing panel was composed of 33 percent CEOs, presidents, or vice-presidents; 30 percent directors; 29 percent managers; and 8 percent academic and consulting marketing specialists. Among Materials panelists, 6 percent were CEOs, presidents and vice presidents; 26 percent were directors; 41 percent managers and supervisors; 16 percent engineering specialists; and 11 percent academic and consulting materials specialists. Approximately 29 percent of the Delphi IX panelists were employed by vehicle manufactures; 63 percent by components and parts suppliers; and 3 percent were others (i.e. specialists, consultants, academics, and representatives of associations and publications).

Presentation of Delphi forecasts and analyses

Data tables. When a question calls for a response in the form of a number, responses are reported as the median value and the interquartile range (IQR). The median is a measure of central tendency that mathematically summarizes an array of judgmental opinions while discounting

extremely high or low estimates; it is simply the middle response. The IQR is the range bounded at the low end by the 25th-percentile value and at the high end by the 75th-percentile value. For example, in a question calling for a percentage forecast, the median answer might be 40 percent and the IQR 35-45 percent. This means that one-quarter of the respondents answered 35 percent or less, another one-quarter chose 45 percent or more, and the middle half of all responses ranged between 36 percent and 44 percent, with 40 percent as the middle response. That narrow interquartile range would indicate a fairly close consensus among the respondents.

In contrast, the percentage forecast for a different question might show a similar median forecast of 40 percent, but with an interquartile range of 20-70 percent, indicating less consensus and a considerable degree of uncertainty about the issue in question.

Uncovering differences of opinion is one of the major strengths of the Delphi method. Unlike other survey methods, where differences of opinion among experts are often obscured by statistical averages, the Delphi highlights such differences through the presentation of the interquartile range.

Discussion. Narrative discussions are presented to highlight and explain a particular set of data.

Selected edited comments. Selected, edited comments from the Delphi panelists are shown following each data table in order to provide some insight into the deliberative process by which panelists arrived at their forecast.

In a Delphi survey, respondents are encouraged to contribute comments to explain their forecast and to perhaps persuade other respondents to change their positions. Many of these edited comments are included. These replies may provide important information which is not evident in the numerical data. An individual panelist may have unique knowledge that planners should carefully consider. However, readers should be careful not to overemphasize a particular comment. It is possible for a well-stated contrary opinion to mislead the reader into ignoring an important majority opinion which is accurately reflected in numerical data.

Manufacturer/supplier comparison. Delphi IX panelists include respondents from the North American automotive manufacturers; the major suppliers of components, parts, and materials for the industry; as well as consultants and academics. A concerted effort is made to obtain a relatively equal distribution of manufacturer and supplier panelists. Within the context of this survey, categorizations will refer simply to either manufacturers (or for brevity in tables, OEMs—Original Equipment Manufacturers) and suppliers.

For obvious competitive reasons, the automotive manufacturers seek to maintain a degree of secrecy regarding their design, engineering, and marketing plans. While the relationship between the manufacturer and supplier is moving toward an increasingly closer degree of cooperation and integration, a considerable element of proprietary concern remains. Additionally, the very size and complexity of the automotive industry works against optimum information transfer. Therefore, where it is considered relevant to a better understanding of or perspective on the forecast, our analyses include a comparison of the forecast from manufacturer and supplier panelists in an attempt to illustrate where significant agreements or differences exist.

Comparison of panels. The three groups of Delphi panelists (technology, marketing and materials) are asked questions that specifically focus on their respective areas of expertise. However, a few questions are considered common to two or more panels. For example, the fuel-price question (see MAT-1) is considered so basic that it was submitted to all three panels.

At times, the panels will give differing responses to these questions. This may reflect the makeup of a particular panel and the panelists' subjective perception of the issue in question. Where differences do exist between the panels, serious consideration should be given to whether the difference reflects the composition and proprietary interest of that particular panel or whether

there exists a substantial degree of uncertainty regarding the issue in question. We try to highlight both the differences and similarities.

Trend from previous Delphi surveys. A single Delphi survey is a snapshot which collects and presents the opinions and attitudes of a group of experts at a particular point in time. Some questions, in various forms, were asked in previous Delphi surveys, and thus provide trend data. The fact that forecasts for a particular question may exhibit considerable variation over the years does not diminish their relevance and importance to strategic planning. The forecasts reflect the consensus of expert opinion at the time. These opinions and forecasts are predicated on the best information available at the time. However, market, economic, and political factors do change. Trend data can reveal the stability or volatility of a particular market, material, or technology issue. A careful analysis of trend data is an important consideration in strategic business planning decisions.

Strategic considerations. Based on the replies to a particular question, other relevant Delphi IX forecasts, other research and studies, and OSAT's extensive interaction with the automotive industry, this report makes inferences and interpretations as to the core issues in questions and their potential impact on the industry. By no means are they exhaustive statements of critical issues. Rather, they are points that the reader might consider useful.

TECHNOLOGY CONTENTS

EXECUTIVE SUMMARY

Automobile manufacturers and suppliers will continue to face many formidable challenges in the next decade as they address environmental issues, tough global competition, and more demanding customers. Furthermore, shortages of capital and skilled human resources and time pressures to do more, better, yet faster, exacerbate their challenges. *The Delphi IX Forecast and Analysis of the U.S. Automotive Industry: Technology* survey identifies many issues facing the industry and provides insight as to industry direction. In a real sense this is a benchmarking study in that it enables any one individual or organization to compare (benchmark) their vision of the future to an industry consensus vision. Panelists expect rapid changes in technology and knowledge, as well as increased regulation and accelerating globalization. Increased reliance on technology to enhance design and manufacturing efficiency is anticipated. Organizations that effectively develop and implement this rapidly changing technology to reduce cost and improve customer satisfaction (increase value) will certainly have a competitive advantage.

The Technology volume of Delphi IX is divided into eight sections addressing Strategic Planning Factors, Engineering and Sourcing Issues, Materials and Recycling, Body and Chassis Product Trends, Safety, Powertrain/Drivetrain, Electrical/Electronics, and Other Issues.

I. STRATEGIC PLANNING FACTORS

Emissions, Fuel economy, and safety standards are expected to be more restrictive over the next ten years. Fuel prices are expected to increase steadily, but moderately, to $1.65 per gallon for regular unleaded gasoline by 2007. High concentration alcohol and natural gas fueled vehicles are expected to comprise 5 percent and 2 percent respectively of North American-produced passenger cars and light duty trucks by the year 2007. Electric vehicle penetration is forecast to be 2 percent, and hybrid electric/combustion engine vehicles are forecast at 5 percent in the same time frame. Furthermore, diesel engines are forecast for 5 percent of passenger cars and 10 percent of light trucks by 2007.

The global warming issue is expected to have a somewhat important influence on automotive design in the next decade. Increased cooperation between traditional North American manufacturers and between traditional manufacturers and suppliers is expected as is cooperation between government and industry.

CAFE standards are expected to increase 16 percent and 20 percent by 2007 for passenger cars and light trucks and vans to 32 m.p.g. and 25 m.p.g. respectively. This is in contrast to stable passenger car CAFE standards of the past eight years and an increase of only 5.8 percent in the last 14 years. Increased passenger car CAFE standards are forecast to present a major challenge to domestic and European manufacturers, whereas Japanese manufacturers are forecast to easily meet these standards because of the large volume of small vehicles that they sell.

Considering the PNGV agreement between the domestic manufacturers and the federal government to pursue development of clean, super-efficient passenger cars, 54 percent of panelists forecast that the goal of 80 mpg can be achieved by the year 2015.

Weight reduction and improved engine efficiency are forecast to make the greatest contributions to improved fuel economy.

Cost and quality are forecast to remain the most important elements of competition in the next decade. Global sharing of vehicle platforms and components within companies is expected to increase moderately. Sharing between companies is forecast to remain relatively unchanged.

II. ENGINEERING AND SOURCING ISSUES

Panelists believe that 70 percent of product design and engineering by traditional domestic vehicle manufacturers for North American-produced passenger cars will be done in North America in 2007 compared to 90 percent today. Foreign based vehicle manufacturers are expected to conduct 30 percent of their product design and engineering for North American-produced passenger cars in North America compared to 10 percent today.

Traditional domestic manufacturers are forecast to source the majority (65 percent in 2007) of parts, components, and subassemblies from the United States, Canada, and Mexico in the next decade. An increasing percentage is expected to be sourced outside of North America, however, including increases in Asia Pacific (excluding Japan), South America and Eastern Europe. North American production operations of foreign-owned vehicle manufacturers are forecast to source 30 percent of parts, components, and subassemblies from Japan in 2007, compared to 40 percent today. Sourcing from North America, is expected to be relatively unchanged. (43 percent in 2007 vs. 40 percent today). Sourcing from Asia Pacific, South America, and Eastern Europe is forecast to increase modestly. Sourcing of components and subassemblies from Mexico by traditional domestic and foreign manufacturers is expected to expand from 10 percent and 14 percent respectively to 25 percent by 2007.

Sourcing of new tooling from North America for North American-produced passenger cars and light trucks is forecast to decrease from 80 percent and 85 percent respectively today to 70 percent in 2007.

Panelists forecast a reduction in product development time for a new platform for both Japanese and U.S. manufacturers in the next decade. The Japanese advantage is expected to be reduced from 6 months currently to 4 months by 2007. Current development cycle times for the United States and Japan are estimated at 42 months and 36 months respectively.

Panelists believe Japan has the most advanced product and process technology today, but expect the gap with the U.S. to narrow in the next decade.

Vehicle engineering using math and computer-based tools (CAE, excluding CAD) is forecast to increase from 30 percent currently to 70 percent by 2007.

III. MATERIALS AND RECYCLING

Panelists forecast reductions in steel and cast iron use of 10 percent and 18 percent respectively, and increases in the uses of aluminum and plastics/composites of 17 percent and 15 percent respectively in the next decade if CAFE increases to 35 m.p.g. The use of aluminum and plastic for exterior body components is expected to increase in the next decade, but steel is forecast to remain the dominant material.

Total vehicle weight reductions of 10 percent for passenger cars and 6 percent for light trucks are envisioned by 2007. The value of a pound of weight saved in a vehicle is forecast to escalate from $1.00 per pound today to $4.00 per pound in 2007, assuming a CAFE requirement of 35 m.p.g. in 2007.

Recycling legislation and regulations are thought to be highly likely by 2007 in the areas of disposal of automotive fluids and used tires, establishment of uniform identification/coding standards to facilitate separation of materials, and recyclability of plastics. Legislation and regulations in several other areas of recycling are thought to be at least somewhat likely.

IV. BODY AND CHASSIS PRODUCT TRENDS

The integral body/frame is expected to remain the major passenger car platform through 2007. Space-frame and separate body/frame construction are forecast to be used in 5 percent and 2 percent respectively of passenger cars in that same timeframe.

MacPherson strut front suspensions are expected to continue in a dominant position in passenger cars (73 percent in 2007), but increased penetration of twin A-arm is forecast. Rear independant suspensions in passenger cars are forecast to increase from 64 percent currently to 75 percent in 2007. Electrical/electronic power steering and hydraulic power steering with electronic control are expected to have penetrations of 10 percent and 15 percent respectively by 2007. Passive-driver selected, semiactive and active suspensions are forecast to attain penetrations of 5 percent, 8 percent, and 2 percent, respectively, by 2007.

Antilock brake penetration on passenger cars is forecast at 80 percent in 2007, while traction control is expected to see an application rate of 20 percent in the same time frame. Four-wheel antilock brakes are expected on 80 percent of light trucks in 2007 compared to 55 percent today.

A small but growing application of tire failure sensing devices (10 percent), puncture resistant/self-sealing tires (20 percent), and run-flat tires (10 percent) is forecast by 2007.

V. SAFETY

Side airbags are forecast for 15 percent of passenger cars and 18 percent of light trucks by 2007. Passenger-side airbags are forecast on 85 percent of light trucks in 2007. Modest use of rear seat occupant airbags is also expected in passenger cars but not on light trucks. Knee bolster airbags are expected to see limited application in the same timeframe. It was assumed that all passenger cars would have airbags for the driver and front passenger and that all light trucks would have driver airbags.

A manual switch to deactivate the passenger-side airbag is forecast for up to 10 percent of passenger cars and 20 percent of light trucks in the next decade. "Smart" airbags are expected to replace most manual switches by 2007 and are forecast for 70 percent of passenger cars and 50 percent of light trucks by that time. Reduced power airbags are forecast for 75 percent of passenger cars and light trucks by 2007.

Other safety features such as in-vehicle message systems, adaptive cruise control and collision warning systems are envisioned in limited numbers over the next ten years.

VI. POWERTRAIN/DRIVETRAIN

For passenger cars, 8-cylinder engine usage is forecast to decline to only 7 percent by 2007, with 4-cylinder engine penetration increasing slightly. Six-cylinder engine penetration is forecast to be unchanged. Similar trends are forecast for light trucks, but with 8-cylinder engine usage at about three times that of passenger cars.

Following trends of recent Delphi forecasts, nearly half of today's engines are forecast to be fundamentally redesigned during the next decade. This will certainly require a major committment of both financial and human resources.

The future role of two-stroke gasoline engines is uncertain but they are still forecast to be in limited numbers (<5 percent) of passenger cars by 2005.

Port fuel injection is forecast in 90 percent of passenger cars with spark ignited engines by 2007, with the balance utilizing direct cylinder injection. A similar trend is forecast for light trucks.

Turbocharging and supercharging of passenger car engines are expected to see minimal application of only 1 percent by 2007. On the other hand, four-valve-per-cylinder engines are

expected on 60 percent of passenger car engines compared to 45 percent in 1996. The increase in multivalve engines is certainly a factor in the low expectations for turbochargers and superchargers.

From 1996 to 2007, push rod valve actuation penetration is expected to decrease from 67 percent to 50 percent in engines with a "V" configuration, while single and dual overhead cam penetrations are forecast to expand to 25 percent and 23 percent respectively. For "in-line" engines, push rod valve actuation is expected to decrease from 10 percent in 1996 to 5 percent in 2007, with single and dual overhead cam penetrations representing 35 percent and 60 percent respectively in 2007. Variable valve timing in passenger car engines is forecast at 25 percent in 2007 compared to a current estimate of 3 percent.

The use of distributorless ignition systems on spark-ignited engines is expected to increase to 90 percent in passenger cars and 80 percent in light trucks by 2007. In the same timeframe, knock/adaptive control is forecast for 80 percent of passenger cars and light trucks. By 2007, cylinder pressure control and individual cylinder control of ignition timing are forecast to see limited applications, whereas coil-on-plug designs are forecast for 20 percent of passenger cars and light trucks. Furthermore, features such as balance shafts, hollow camshafts, and roller lifters are all expected to expand in the next decade.

The use of aluminum in cylinder heads and blocks in passenger car engines is expected to increase to 90 percent and 24 percent respectively by the year 2003. The use of aluminum in cylinder heads and blocks in light trucks is forecast to increase also. Several applications of plastic engine components (intake manifolds, valve covers, fuel rails, throttle bodies, oil pans) are expected to see significant use, while ceramic engine components are forecast to see limited application by the year 2007.

Electrically heated catalytic converters and start-up converters are believed to be required in some applications to meet both federal and California emission standards over the next decade. Metal substrates are forecast for 15 and 20 percent of catalytic converters to meet federal and California emission standards respectively.

The five-speed manual transmission is expected to be the only manual transmission for passenger cars with any significant volume in the next decade. The decline of the three-speed automatic transmission is forecast to continue in favor of four-speed designs, with only 5 percent three speeds forecast for 2007. Five-speed automatic transmissions are forecast to emerge in upscale vehicles (5 percent). Continuously variable transmissions are forecast in 4 percent of passenger cars by 2007. In that same timeframe, sequential shift automatic transmissions and automatic transmissions without torque converters are forecast for 5 percent of passengers.

Transmission configurations for light trucks are forecast to be very similar to those of passenger cars in the next decade. CVT transmissions are not forecast to be used in light trucks, however.

In the opinion of our panelists, front engine, front drive will continue to be the dominant drivetrain configuration in passenger cars (90 percent).

VII. ELECTRICAL/ELECTRONICS

Total vehicle combined electrical and electronic cost, as a percent of total vehicle cost, is forecast to expand from a current estimate of 20 percent to 24 percent in 2007. Vehicle electronic content is expected to continue to grow, from a 1997 estimate of 13 percent of total vehicle cost to 19 percent by 2007. Vehicles with at least one major multiplexed power system are forecast to expand from a current market estimate of 3 percent to 23 percent by 2007 with some limited use of fiber optics in the control. Cost, packaging and weight reduction are the important potential advantages of multiplexing.

Application of electronic/electrical features such as antitheft, CD player, electronic keyless entry, and onboard diagnostic via expert systems is expected to increase significantly in the next decade. Minimal use of increased systems voltage is forecast in the next decade (6 percent). The number of electric motors in a vehicle is anticipated to increase approximately 30 percent by the year 2007.

VIII. OTHER ISSUES

The following vehicle maintenance features are forecast for 75 percent or more of passenger cars by 2007: 100,000-mile maintenance-free engine (except oil filters); chassis lubed for life of vehicle; 10-year body corrosion warranty (perforation); 50,000-mile/5-year coolant; 100,000-mile maintenance-free transmission (including fluids).

Skilled labor supply deficiencies have been identified for the near and long term. Management of human resources is expected to be a critical challenge for the industry over the next decade.

Panelists estimate that technical employees currently spend 40 hours per year in continuing education, and that this will increase to 80 hours per year by 2007. By 2007 it is forecast that 50 percent of continuing education will be conducted in a classroom and 30 percent in a "virtual college" setting. This compares to 80 percent in a classroom and 5 percent in a "virtual college" currently.

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TECH-1a. Please estimate U.S. retail fuel prices, per gallon, for 2002 and 2007, including fuel tax. (Please use constant 1997 dollars without adjusting for inflation.)

		Median Response		Interquartile Range	
Unleaded Gasoline	**1996***	**2002**	**2007**	**2002**	**2007**
Regular	$1.23	$1.41	$1.65	$1.35/1.50	$1.42/2.00
Premium	1.40	1.62	1.80	1.50/1.75	1.60/2.25

* **Source:** U.S. Energy Information Administration, National Average Jan. - Oct. 1996.

Selected edited comments

- China's demand for oil will raise the price of crude.
- Estimates are based on increased taxes to provide incentives for alternative fuel vehicles.
- Fuel economy legislation will be replaced by fuel tax.
- Fuel just does not seem to have much price fluctuation. Improved recovery techniques and efficiencies of scale still hold the price down. There is also the possibility of agricultural-based fuels including alcohol's, which become more of a competitive restraint as prices increase. Only a change in attitude toward fuel taxes could have any significant effect on prices
- Higher taxes are expected whereas gasoline price without tax remains about the same.
- I expect a stable oil market with price increases keeping pace with inflation. As always there will be pressure to add additional state and federal taxes. Oxygenated gasoline will also cause price increases.
- Increasing fuel price is the only way to control CO_2.
- New formulations of gasoline for emissions and revenue for roads are needed.
- The only pressure to increase the price of fuel will be "reformulation" to reduce emissions, and this should only be a few cents per gallon.
- The supply appears unrestricted through the foreseeable future: no political/organized strengthening of supplying nations to restrict supply seems likely. The demand will be more constant; fuel efficiency gains will be offset by more driving.
- This assumes no oil shocks and no taxation policies like Europe, Japan et al. It further assumes no "carbon taxes" to control greenhouse gases in that time frame.
- This estimate is based on a recent comment by the chairman of Texaco; that the oil or fossil fuel supply will (due to extremely favorable "new finds" of oil/gas drilling) outstrip demand for the foreseeable future.
- This is dependent on the outcome of the 2000 presidential election.
- This questions assumes a stable Middle East—who knows?
- Unless there is an oil scare, prices will be stable. By 2007, government will step in to control consumption by raising tax.

Discussion

Delphi IX technology panelists anticipate the prices of regular and premium gasoline to increase at rates of approximately 3 percent per year in 1997 dollars through 2007. This increase is consistent with recent forecasts, but is significantly lower than those of early Delphi forecasts that were conducted at the time of gasoline shortages.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Comparison of forecast: MAT-1 and MKT-3a

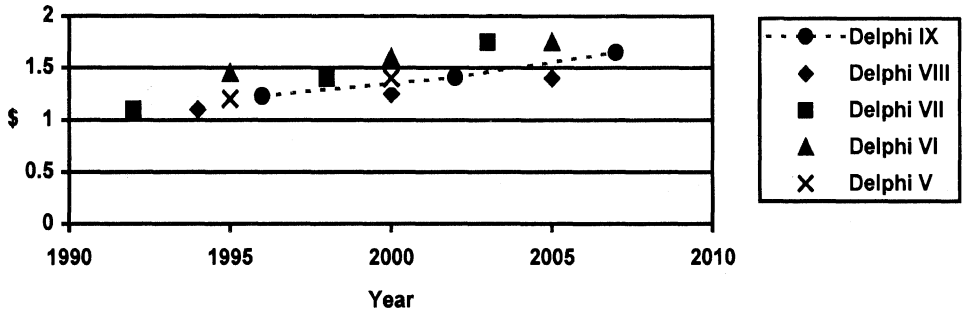
Responses from materials and marketing panelists are not statistically significantly different from technology panelists.

Trend from previous Delphi surveys

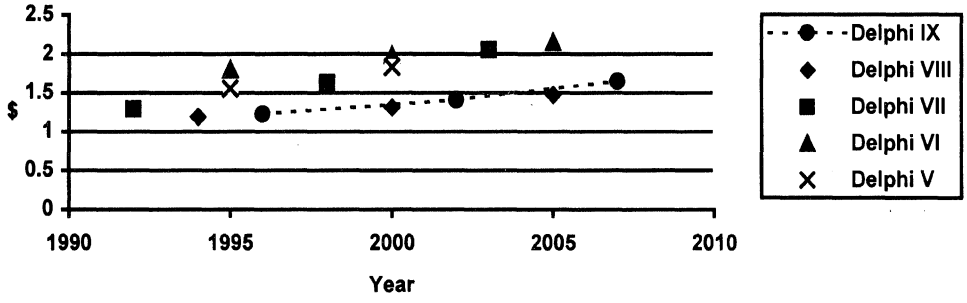
The following graphs compare the prices of gasoline for this and the previous three Delphi forecasts in actual dollars at the time of the survey and also in constant 1997 dollars.

Unleaded Regular Gasoline:

Regular Fuel (Actual Price at Time of Forecast)

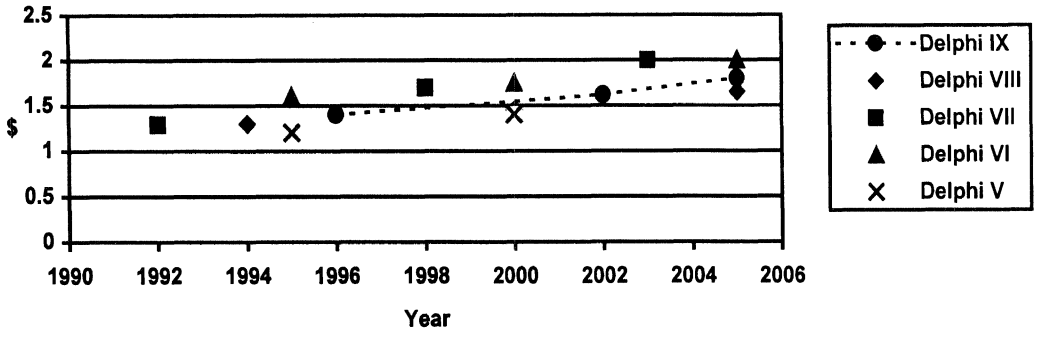


Regular Fuel Price Forecast (1997 Dollars)

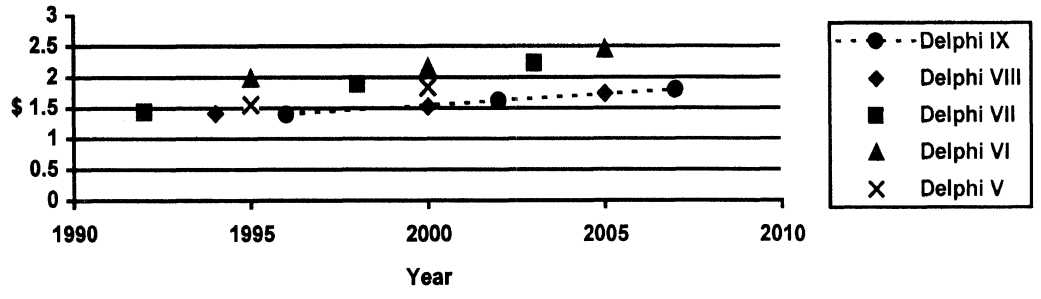


Unleaded Premium Gasoline:

Premium Fuel (Actual Price at Time of Forecast)



Premium Fuel Price Forecast (1997 Dollars)



Prices for regular and premium fuel are forecast to increase, but to levels on the low side of previous forecasts. The price of regular gasoline increased from $1.10 to $1.23 per gallon from 1994 to 1996. The price of premium gasoline increased from $1.30 to $1.40 per gallon in the same time period. Prices for both regular and premium gasoline were unchanged from 1992 to 1994. Prices of gasoline have increased very near to the rate of inflation during the period 1992-1996.

Strategic considerations

Gasoline prices are forecast to increase at a rate greater than the rate of inflation for the next decade. This is in spite of price increases near the rate of inflation for the past four years. Price increases are forecast to be near or below previous forecasts.

The forecast for the continuation of low gasoline prices relative to the rest of the world will continue to create difficulties for vehicle manufacturers in meeting corporate average fuel economy standards (CAFE). Many consumers will continue to choose large vehicles that have relatively high fuel consumption because of the low fuel cost penalty. This may also hinder efforts to reduce the emissions of carbon dioxide, which are blamed by many for global warming. Global warming is a controversial issue regarding both its presence and potential causes. However, the forecasted increase in gasoline prices, although moderate, may have some impact on the size and fuel efficiency of vehicles purchased.

Some panelists commented that the above forecasts assume there is no disruption of the oil supply due to political or other problems in the oil-producing countries. Vehicle manufacturers should have contingency plans for unforeseen disruptions in the oil supply. These plans may include flexibility in assembly plants to build more small vehicles and the ability to produce components for these vehicles.

Some of the factors that may influence the price and availability of gasoline are:

- world political stability
- federal and state taxes
- the continued need by petroleum-exporting countries to finance their economies through exports of petroleum
- the availability of alternative energy sources and the viability of consumer markets for those products
- increases in product energy efficiency as a result of legislation, market demand or technological improvements
- increasing demand by rapidly developing countries
- declining petroleum reserves in the United States
- potential new major discoveries of petroleum reserves throughout the world.

TECH-1b. What percentage of the change forecast in Tech-1a will be attributed to state and federal taxes?

Percent Change Attributed to Taxes			
Median Response		Interquartile Range	
2002	2007	2002	2007
50%	50%	20/75%	25/80%

Selected edited comments

- Gas taxes will be an area of revenue for state and local governments to reinvest in road construction projects and other general funds. Gas taxes have been avoided in the past, but it seems likely, the future will be different.
- I estimate a 10 percent increase every five years to rebuild U.S. highway infrastructure.
- Most likely all of the increase will be due to taxes.
- Most of the change will be due to legislative pressures.
- Road systems are crumbling. Revenue from increased price is assumed to be applied to road reconstruction.
- The infrastructure is in need of repair, more than routine maintenance. User taxes will increase to finance the repairs.
- The need to fix the crumbling infrastructure will slowly prevail over the political sensitivity of a tax increase.
- This is dependent on the outcome of the 2000 presidential election.
- We will again begin to realize that we have finite resources.

Discussion

Panelists forecast that half of the gasoline price increases in the next decade will be a result of state and federal tax increases. Several panelists noted that the increased tax revenue will be used for road and infrastructure repair.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Comparison of forecast: MAT-2 and MKT-3b

Responses from materials panelists are not statistically significantly different from technology panelists. There is a statistically significant difference in responses between technology and marketing panelists. Mean responses for the two panels are summarized in the following table.

Percent Change Attributed to Taxes		
	Technology	Marketing
2002	47%	36%
2007	53	42

Trend from previous Delphi surveys

This question was not asked in previous Delphi forecasts.

Strategic considerations

Roads and bridges are in need of repair throughout the country. Panelists have forecast that taxes will be increased in the next decade to fund these repairs. The effect on the automotive industry may be that there will be some shift to smaller more fuel-efficient vehicles as fuel prices increase.

Another effect may be that fewer new vehicles are sold as the total cost of vehicle ownership increases. Vehicle affordability, including operating expenses, is currently a problem for many prospective vehicle buyers.

Clearly, at the federal level there is great concern over the willingness of consumers (who are also voters) to accept higher fuel taxes. We find evidence for this in the meager tax increase of slightly over four cents a gallon in the deficit-reduction tax package of the early '90s. Fuel taxes are definitely a "tough sell." Thus the burden for fuel economy improvements will likely be placed on the automotive manufacturers with limited support from market forces.

The large interquartile range in responses indicates uncertainty with regard to this issue.

TECH-2. How important will global warming be in driving automotive design and regulation in 2002 and 2007?

Scale: 1 = extremely important 3 = somewhat important 5 = not at all important

Mean Response	
2002	3.7
2007	2.9

Additional Responses:

Third World - 5; developed countries versus Europe - 3

Selected edited comments

- Fuel cost will be a much bigger issue.
- Global warming is considered by most as imaginary.
- I anticipate that counterforces eventually will temper somewhat the influence of global warming alarmists.
- Likely design pressure will come from increased CAFE standards.
- Real or perceived contribution to global warming will drive CAFE increases.
- The impact of the automobile on global warming and the actual warming changes have been grossly overestimated. By gathering and analyzing the data over a longer time period, I think that this will be shown.
- The industry and the public are becoming increasingly aware of and are showing serious concern with respect to global warming. In spite of the rapid rise in "high-fuel-consumption" vehicle (truck) sales, the future trend is to significantly reduce fuel consumption and CO_2 emissions.
- There is not convincing evidence that global warming is a real threat. Lacking overwhelming proof, attention will be diverted to other public issues.
- There is so much contradictory evidence in regard to global warming at this time that there will be little near-term effect. Secondly, the infrastructure to support alternative fuels does not exist or is in its infancy.

Discussion

Panelists forecast that global warming will be somewhat important in driving automotive design and regulation in the next decade.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was not asked in previous Delphi forecasts.

Strategic considerations

Although there is considerable controversy regarding the presence and causes of global warming, panelists forecast that this issue will have some impact on vehicle design in the next decade.

Possible influences of global warming on automotive design and regulation include the following:

- increased use of lighter materials and more efficient structures for improved economy
- increased use of alternative power plants to improve fuel economy and/or allow the use of nonhydrocarbon fuels
- regulations mandating car pooling or the use of public transportation
- increased fuel economy standards
- increased gasoline taxes or carbon tax

While the industry has concentrated on the economic thrust of global-climate-change policies, there is also an opportunity to literally obsolete today's vehicles—creating a potential market boom. We will likely see more positive, proactive strategies emerge from many of the vehicle manufacturers.

TECH-3. What do you expect CAFE (Corporate Average Fuel Economy) standards for passenger cars and light trucks and minivans will be in 2002 and 2007?

	CAFE Standards				
		Median Response		Interquartile Range	
Vehicle Type	1997*	2002	2007	2002	2007
Passenger cars	27.5 mpg	29.0	32.0	27.5/30.0	30.0/33.4
Light trucks and minivans	20.7 mpg	22.0	25.0	21.5/24.0	23.0/27.8

*Source: U.S. Environmental Protection Agency.

Selected edited comments

- Alternative-fuel vehicles may require a different regulation by 2007.
- As boomers forsake station wagons and minivans for sport utility vehicles, CAFE numbers will be a problem even if the standards don't change.
- Assuming no crisis in oil, car manufacturers will be successful in lobbying for no increases in CAFE.
- CAFE should be abolished. It has never done anything but distort the market and shift the market to light trucks.
- CAFE will place a lot of pressure on light trucks due to their popularity.
- Government and industry will work together for modest increases in the requirements.
- Higher light truck CAFE standards will make foreign manufacturers more competitive. Some restraint will therefore be shown in raising the light truck standard.
- Introduction of EVs and hybrid vehicles will impact the average for passenger vehicles, along with some new engine technology. Trucks will not be affected as much due to the high mix of large trucks.
- It depends on political climate.
- Light truck and minivan classification will go away—all will be classified as passenger vehicles up to 6,000 lbs. GVW.
- Light trucks will come under severe short-term scrutiny as market share peaks in the next few years.
- More attention will be directed at minivans as they constitute such a large portion of the vehicle population.
- Most emphasis will be on improving fuel economy for light trucks/minivans due to the increasing percent of sales.
- The 2000 presidential election will have a major impact on future CAFE (either little change or a significant increase).
- The biggest change will be for trucks. Congress will eventually realize we will someday run out of oil.
- The definition of "light trucks and minivans" qualifying for the less demanding CAFE standards is likely to change, based on primary vehicle usage/intent.
- These are based on the assumption that SUV and luxury SUV (e.g., Mountaineer/Navigator) popularity and the trend away from the conventional luxury vehicles, i.e., cars and personal

luxury/specialty cars (e.g., Thunderbird) will force EPA to reclassify "passenger" SUVs/Vs commercial vehicles for CAFE purposes.

- This depends on the possible reclassification of minivans and SUVs to passenger car status.
- Unless prices double, U.S. consumers will revolt and the CAFE law will be repealed.
- Vice President Al Gore, if elected president, will force mpg standards to economically risky levels.

Discussion

Passenger car CAFE standards have been unchanged since 1990 and light truck CAFE standards since 1991. Panelists anticipate increases of 16 and 21 percent for passenger cars and light trucks respectively by the year 2007, however.

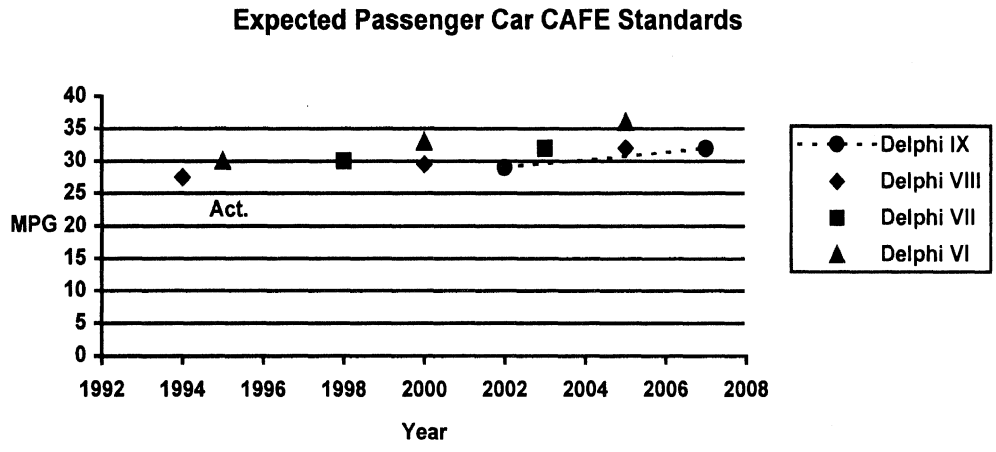
Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers only for CAFE standards for passenger cars for 2002. Manufacturers forecast a mean value of 28.7 mpg whereas suppliers forecast 29.7 mpg. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

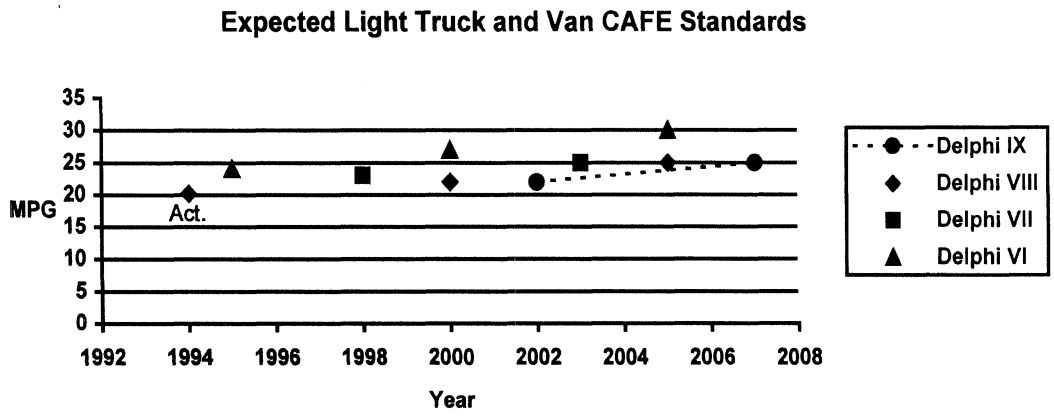
Trend from previous Delphi surveys

This question was first asked in Delphi VI. Results from previous Delphi forecasts are compared to those of the current forecast in the graphs below.

Passenger Cars:



Light Trucks and Vans:



Current panelists forecast similar increases in CAFE standards to those of the previous two panels. With each successive forecast, however, the timing of the increase is delayed two years. Panelists in the 1991 Delphi VI survey forecast higher standards for passenger cars and light trucks in 2005 than current panelists forecast for 2007.

Strategic considerations

Any increase in passenger car and light truck CAFE standards would create a significant challenge to the vehicle manufacturers. With a forecast for only moderate increases in fuel prices, the consumer would have little incentive to purchase more fuel efficient vehicles. As a result, the burden will be on the manufacturer to produce vehicles that offer the same utility as current vehicles, but provide improved fuel economy. Increasing fuel economy by conventional means such as increased use of more costly lightweight materials will be met with resistance by the consumer, as vehicle prices would likely increase to cover higher material costs.

The real challenge is to provide improved fuel economy without a commensurate increase in cost. This may be possible through increased use of computer modeling and other advanced technologies, leading to lighter structures, more efficient engines, and other factors. It is likely that most manufacturers will make a good faith effort to improve fuel economy to circumvent introduction of more restrictive standards.

The global-warming issue may be a driver of increased CAFE standards. The current administration in Washington appears receptive to committing the United States to a reduction of carbon dioxide emissions. An increase in CAFE standards may be one element in approaching such a reduction.

As noted by a number of the panelists, the large-scale move by consumers from passenger cars to sport utility vehicles may cause a reclassification of sport utility vehicles as passenger cars. This would have the net effect of a significant increase in passenger car CAFE standards.

Clearly, the forecast change in the light truck standards would have the greatest impact considering the growth in popularity of this segment and the generally higher profitability of these vehicles. Proportionally, the impact would be greatest on the traditional domestic manufacturers.

TECH-4. Please forecast the change in passenger car gas guzzler requirements for 2002 and 2007.

Passenger Car Gas Guzzler Requirements				
	Median Response		Interquartile Range	
Current	2002	2007	2002	2007
22.5 mpg	23.5 mpg	25.0 mpg	22.5/24.0 mpg	23.1/26.0 mpg

Selected edited comments

- A gas guzzler tax will be put on SUVs and will be increased on passenger cars to get people into small cars.
- Assuming no crisis in oil, car manufacturers will be successful in lobbying for no increases in CAFE.
- Consumers' desire to buy what they want will force the end of this law.
- I do not see an emphasis on this area.
- I expect guzzler requirements to track CAFE requirements, with the differential holding at about 5 mpg.
- I see no need for it to change.
- I think this requirement will be dropped as manufacturers introduce new, more fuel-efficient vehicles and alternate-fuel vehicles. The need for government pressure will be reduced.
- The emphasis will shift towards the SUVs.
- This is a particularly onerous tax. Requirements are unlikely to be increased.
- This seems to be a low-profile issue.

Discussion

Panelists forecast an increase in passenger car gas guzzler requirements from 22.5 mpg currently to 23.5 mpg in 2002 and 25.0 mpg in 2007.

Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers for both 2002 and 2007. The differences are summarized in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

Passenger Car Gas Guzzler Requirements			
2002 Mean		2007 Mean	
Mfr.	Supp.	Mfr.	Supp.
23.2	24.1	24.3	26.4

Suppliers forecast higher gas-guzzler requirements in the future than manufacturers.

Trend from previous Delphi surveys

This question was not asked in previous Delphi forecasts.

Strategic considerations

Gas guzzler requirements apply to individual models, whereas CAFE standards apply to the total fleet-weighted average of a manufacturer. An individual model that does not meet gas guzzler requirements can have a significant cost penalty which increases as the shortfall to the requirement increases.

The public image of the manufacturer may also be negatively impacted if a model is labeled a gas guzzler. Consequently, manufacturers may be willing to add significantly to the cost of a vehicle that does not meet gas guzzler requirements. These cost increases may be applied to premium materials, more costly powertrain components, low rolling-resistance tires, or other components that will improve fuel economy.

There are currently no gas guzzler requirements for light trucks.

TECH-5. What passenger car and light truck CAFE standards can the three traditional domestic manufacturers and other full-line vehicle importers reach, with reasonable effort, in 2002 and 2007? (Reasonable effort means utilizing practical technology, avoiding substantial reduction in passenger and luggage space, and avoiding excessive costs for manufacturers and suppliers.)

		Median Response		Interquartile Range	
Manufacturers	**1996 achieved***	**2002 mpg**	**2007 mpg**	**2002 mpg**	**2007 mpg**
Passenger Cars					
Traditional domestic	27.9 mpg	30.0	32.0	28.5/30.0	30.0/34.0
Japanese – foreign and domestic	30.5 mpg	32.0	35.0	31.0/33.0	33.0/36.0
European – foreign and domestic	26.9 mpg	29.0	32.0	28.0/30.0	29.6/33.0
Light Trucks					
Traditional domestic	20.6 mpg	22.0	25.0	22.0/23.0	23.0/27.0
Japanese – foreign and domestic	22.6 mpg	24.0	27.0	23.0/25.0	25.0/28.5
European – foreign and domestic	17.1 mpg	20.0	22.0	19.0/22.0	20.0/25.0

* Source: American Automobile Manufacturers Association; Motor Vehicle Facts and Figures 1996; Ward's Automotive Reports, January 13, 1997.

Selected edited comments

- "Reasonable effort" should include "marketing," i.e., pricing, etc. Auto manufacturers can't sell what people don't want. Japanese vehicles are gaining weight and four-wheel-drive inefficiencies.
- 2002 is too soon to take significant weight out of these vehicles without major investment costs to the manufacturers. In 2007, the only way to achieve light truck fuel economy improvements will be through significant weight reduction and more expensive powertrains. A breakthrough in lean nitric oxide catalysis will also be required.
- A recent Detroit News article indicated a shortfall in CAFE for the Big Three in trucks. All will fall short. Ford will miss passenger CAFE as well. It is achievable through model restriction and corresponding lower profit.
- Contrary to government belief, CAFE will be driven by customer demand. If consumers continue to demand large cars and trucks, CAFE increases will be moderate. Alternate fuel vehicles and EVs will be introduced, but they will remain niche vehicles in relatively small packages. Europeans are aggressively pursuing alternate fuels for their home market which could be brought to the U.S. Additionally, they are entering the mini-SUV market.
- Designing and building for improved fuel economy is reasonably straightforward. Consumer acceptance is much more complex to estimate or predict.
- Diesel engines will return, along with their benefits.
- Dramatic changes are not in the works for 2002. It will take a big effort to get 8-10 percent improvement in 2007. Most of the improvement will come from reduction of driveline dissipative losses and improved electric control of vehicle performance.
- I estimate 1 mpg improvement every 5 years for cars, 1.5 mpg for trucks.
- I see no major incentive to change unless CAFE standards change.

- Larger improvements are possible in the light truck/minivan segment.
- Light trucks require power for towing and weight for toughness. Cost prevents significant weight reduction. The main technology allowing improved BSFC will be direct injection/lean burn.
- Size and weight reductions are the only practical way to achieve fuel economy. Customers won't tolerate the loss of function this will entail.
- The most critical element in forecasting CAFE is not technology, but the mix of vehicles that customers wish to purchase, which in turn is largely a function of gasoline prices. If gas prices remain low and consumers continue to want trucks and large cars, it may not be possible to achieve any increase in CAFE standards at all.
- These estimates are based on the rapid rise in popularity and sales of the "heavy" SUV (Expedition/Tahoe class) and "small" SUV (Toyota RAV4 class) vehicles.
- Today's technology is sufficient to increase fuel economy significantly over today's levels. Legislation and taxation will be required to force manufacturers and vehicle purchasers to desire fuel-efficient vehicles.

Discussion

The following charts show the anticipated CAFE requirement versus attainable values for traditional domestic, Japanese, and European manufacturers, based on forecasts of our current panelists.

Passenger Car:

Achievable Passenger Car CAFE			
	1996* mpg	**2002**	**2007**
CAFE requirement (forecast) (Ref.: TECH-3)	27.5	29	32
Traditional domestic	27.9	30	32
Japanese – foreign and domestic	30.5	32	35
European – foreign and domestic	26.9	29	32

*Source: American Automobile Manufacturers Association; Motor Vehicle Facts and Figures 1996; Ward's Automotive Reports, Jan. 13, 1997.

Attainable *passenger car* CAFE levels are forecast to be as follows for the years 2002 and 2007:

Traditional domestic	→	at or above CAFE standard
Japanese – foreign and domestic	→	above the standard
European – foreign and domestic	→	at the standard

Light Trucks:

Achievable Light Truck CAFE			
	1996* mpg	**2000**	**2005**
CAFE requirement (forecast) (Ref.: TECH-5)	20.7	22	25
Traditional domestic	20.6	22	25
Japanese – foreign and domestic	22.6	24	27
European – foreign and domestic	17.1	20	22

*Source: American Automobile Manufacturers Association; Motor Vehicle Facts and Figures 1996; Ward's Automotive Reports, Jan. 13, 1997.

Attainable *light truck* CAFE levels are forecast to be as follows for the years 2000 and 2005:

Traditional domestic → at the CAFE standard
Japanese- foreign and domestic → above the standard
European- foreign and domestic → below the standard

Manufacturer/supplier comparison

Responses for manufacturers and suppliers are statistically significantly different for the areas noted in the following table. Please note that mean values are used in determining if there is a statistical difference, and mean values are compared in this analysis whereas median values are reported in the original question.

Attainable CAFE Standards Forecast				
Manufacturers	**2002 Mean**		**2007 Mean**	
	Mfr.	**Supp.**	**Mfr.**	**Supp.**
Passenger Cars				
Traditional domestic	29.2	30.4	31.4	34.1
Japanese – foreign and domestic	--	--	33.4	36.6
European – foreign and domestic	28.6	29.9	30.9	33.7
Light Trucks				
Traditional domestic	22.2	23.1	24.1	26.3
Japanese – foreign and domestic	23.9	24.9	25.8	28.2
European – foreign and domestic	19.7	21.1	21.7	24.5

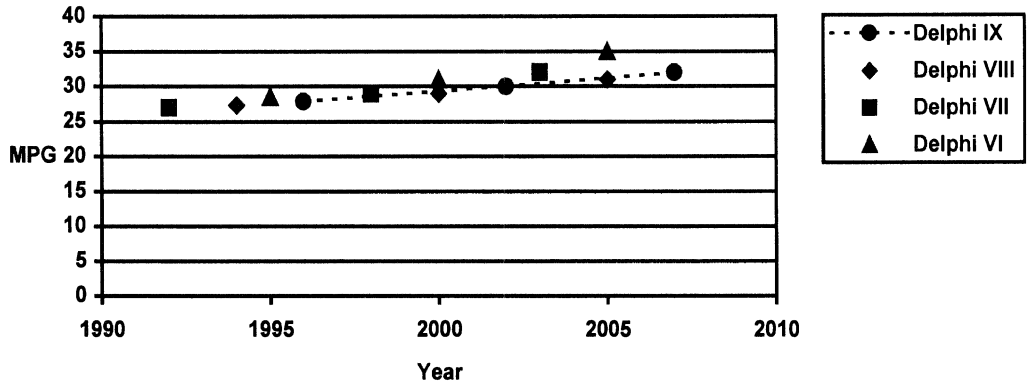
In all cases, suppliers forecast significantly higher attainable CAFE standards than did manufacturers. CAFE is a function of model mix as well as many other technical factors. It is likely that manufacturers have better sources of information for calculation of CAFE than suppliers.

Trend from previous Delphi surveys

This question was asked for light trucks for the first time in the 1996 Delphi VIII survey. The question was asked for passenger cars for the first time in the 1992 Delphi VI survey. The numbers are comparable for domestic manufacturers, but the full-line foreign manufacturers from all countries were lumped together in the 1992 Delphi VI survey. Results for foreign manufacturers from the 1994 Delphi VII and 1996 Delphi VIII surveys are comparable.

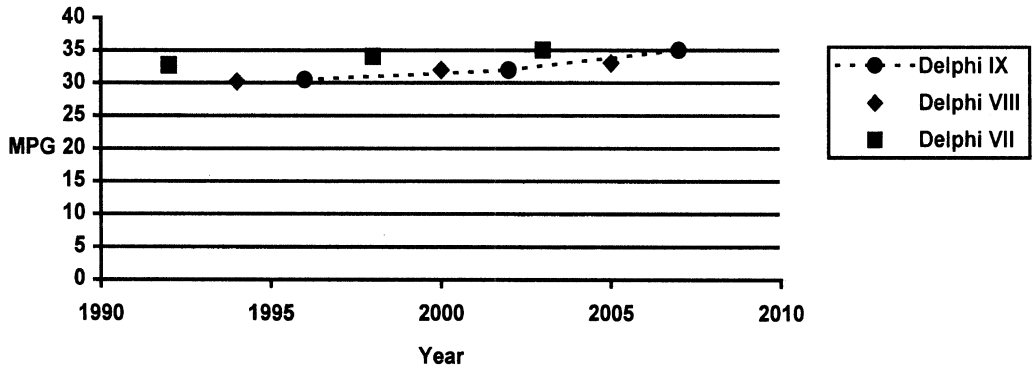
Passenger Cars:

Attainable Traditional Domestic Manufacturer CAFE Forecasts



The expectations for future attainable CAFE in the current survey are at or below those of the previous three surveys for the traditional domestic manufacturers.

Attainable Japanese Manufacturer CAFE Forecasts



The expectations for future attainable CAFE in the current survey are at or below those of previous surveys for the Japanese – foreign and domestic manufacturers.

Light Trucks:

Results of the current survey and the 1996 Delphi VIII survey for light trucks are in general agreement.

Strategic considerations

Panelists forecast that traditional domestic and European manufacturers will struggle to meet passenger car and light truck CAFE standards for the next decade, whereas Japanese manufacturers will be well above the standards. This is primarily because of the smaller size of the average Japanese vehicle. This will allow Japanese manufacturers to focus on future products without a concern for fuel economy.

Traditional domestic and European manufacturers, on the other hand, will be required to develop and execute strategies for fuel economy improvement. This will add cost and manpower to the product development process, and may add piece cost to vehicles for premium materials or components. In addition, traditional domestic and European manufacturers may be required to artificially control product mix so that more high fuel economy vehicles are sold. This may affect corporate profits, since the less fuel-efficient vehicles are, in many cases, the most profitable.

CAFE is a less than perfect approach to reducing fuel consumption. Some automotive executives have stated that increasing the price of gasoline would be a superior approach. There is merit to this argument, in that it shifts the choice between total vehicle operating cost and vehicle function to the consumer. Our panelists have not forecast a significant move in this direction in the next decade, however (Ref. TECH-1a).

With the increased interest in advanced technology (particularly powertrains) it may be possible to achieve significant mpg improvement in the time frame of the forecast. For example, direct-injection diesel (assuming it can meet emission requirements) could lead to a great improvement in light-truck fuel economy—albeit at a modest cost penalty. It is important for all industry participants to monitor technology closely to minimize surprises. The rate of technological development is rapidly increasing across the globe.

TECH-6. What percentage improvement in fuel economy will be attributed to each of the following sources by 2002 and 2007? Percent improvement is approximately: (mpg improvement/current mpg) x 100. Please use the fuel economy of current vehicles as the baseline for all forecasts.

Sources	Median Response		Interquartile Range	
	2002	2007	2002	2007
Accessory drives	2%	3%	2/3%	2/4%
Aerodynamics	2	3	1/3	2/5
Downsizing	3	5	2/5	3/7
Engine efficiency	5	10	4/8	6/12
Reduced tire rolling resistance	2	3	1/2	2/3
Supercharger/turbocharger with engine downsizing	2	4	1/3	2/5
Transmission efficiency	3	5	2/5	3/6
Weight reduction without downsizing	4	7	2/5	4/10

Other Responses:

Alternate fuel – 2002: 10%; 2007: 15%

Alternate fuels/hybrid – 2002: 10%; 2007: 20%

Brake system and exhaust system tuning – 2002: 3%; 2007: 5%

Braking system – 2002: 2%; 2007: 3%

Diesel and low performance – 2002: 60%; 2007: 70%

Electrical load management – 2002: 1%; 2007: 2%

Fuel – 2002: 5%

Idling reduction – 2002: 8%; 2007: 10%

Improved vehicle design and powertrain matching – 2002: 3%; 2007: 20% (Based on the understanding that several new technologies currently under development will mature for the year 2007.)

Material substitution – 2002: 5%; 2007: 5%

New technology not invented – 2002: 14%; 2007: 29%

Regenerative braking – 2002: 2%; 2007: 6%

Smart control of engine and accessories – 2002: 15%; 2007: 25%

Smart electronic control of engine and accessory devices – 2002: 10%; 2007: 20%

Switch to diesels – 2002: 9%; 2007: 19%

Total powertrain (transmission/engine system) – (replaces individual listings above) – 2002: 4%; 2007: 10%

Selected edited comments

- 2002 products are already in the development pipeline and there is no opportunity to do any major downsizing or changes. Therefore the percent F/E improvements will, by definition, be very small here in North America. Similarly, at $1.25/gallion, the customers interest in increased F/E is low and will not be a major driver for change for the 2007 models.
- Assumptions for estimates: U.S. domestic vehicles only; market share for passenger cars equals 60 percent; market share for light trucks/vans equals 40 percent.
- By 2007, CVTs will have made significant inroads. Direct injection gas and common diesels will

be acceptable in North America.

- Cost/economics versus value obtained will continue to constrain the solution set. More efficient, conventional powertrains will provide the greatest gains in fuel economy with the fewest tradeoffs to the customer.
- Downsizing engines, car size, product mix, and weight is the only solution. Hybrids will be user unfriendly.
- Downsizing in the U.S. is likely, based on the prospect of the global leveling of fuel prices and/or a fuel crisis.
- Downsizing is dependent on regulation, which is dependent on the 2000 election.
- Downsizing is not an option at this time.
- Downsizing: The increase in the shift to larger cars and SUV will level off and we will see a drop in average size of vehicle purchased. The vehicles available will not downsize, but consumer selection will (on the average).
- Downsizing: Weight reduction is almost linear with fuel economy, i.e., 10 percent less weight, 10 percent more fuel economy.
- Engine efficiency improvements will require new engine technologies, such as DI and/or PFI lean burn. Efficiency improvements may be mandated through CO_2 control legislation. Buy a Cadillac, get a free GEO.
- Engine improvement (such as direct injection) and hybrid vehicles are main contributors.
- From today (1998) forward, there is a 35 percent potential improvement in internal combustion engine efficiency, i.e., DI (gasoline, throttle plate elimination), low friction, etc.
- I assume an average of 20 percent total improvement over each five-year period.
- Light trucks should be able to get significant improvement from a variable displacement strategy (4/8 cylinders) or other variable valve-timing function. These can provide the performance needed for high-load capacity and performance when needed but yield improved fuel economy (15 percent) for the majority of their light-load duty cycle.
- Lightweight structures in SUVs will boost CAFE performance with minimal downsizing by 2007.
- Major gains will come from continuously variable transmissions and from switching to diesel and hybrid diesel power. Also, direct-injected gasoline engines will help improve economy.
- Manufacturers are waiting on government changes/direction in policy. Environmental requirements may force even more reductions.
- Powertrain efficiency improvements will be the largest main contributors to increased fuel economy. Customer expectations, economic factors, and tradeoff's will constrain the contribution of chassis and body initiatives.
- Reduction or elimination of engine idling can have significant impact on fuel economy.
- Smart control of gasoline and EV, such as HEV, will provide a drastic increase in fuel economy. For instance, in the case of the Toyota hybrid system, fuel economy gain is around "X" percent. The "X" value would depend on the definition of mileage calculation.
- Smart controls for many manual systems on the vehicle will become practical. Optimized demand for operating-mode changes in the engine will become standard by 2007. Over and under control and dithering will be eliminated. Control of vehicle handling will supplement the drive-mode controls.

- Sooner, rather than later, we must find a way to high yield fuels. Unfortunately, inefficient systems still waste almost half the fuel energy.
- The buying public will not accept further downsizing in the near future.
- The picture can change (however unlikely) should major breakthroughs occur in alternative powertrain technology.
- The public will expect power and performance to remain at current levels.
- These estimates are for Japanese cars. Less improvement is expected for traditional American cars. Tighter emission standards and safety standards mean more cost to meet these requirements. This leaves less potential for weight reduction and advanced engine technology to improve fuel economy.
- Tire rolling resistance could become more significant if vehicle weight reduction is significant.
- Transmission efficiency – CVTs are coming for the medium/small cars.
- Vehicle size will tend to increase rather than decrease in the midsize range.
- Weight reduction without downsizing will occur through the use of alternate materials and design efficiencies.
- Without significant increases in fuel cost, there is no possibility of downsizing.

Discussion

Panelists forecast that the most significant improvements in fuel economy by 2007 will come from engine efficiency (10 percent) and weight reduction without downsizing (7 percent).

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was asked in this format for the first time in the 1996 Delphi VIII survey. Although the format was different in earlier surveys, engine efficiency and weight reduction were forecast to contribute the most to fuel economy improvement.

Results of the current and preceding survey are in close agreement.

Strategic considerations

Panelists forecast that improved engine efficiency and weight reduction without downsizing will have the greatest contributions to fuel economy improvement by 2007. Significant changes in fuel economy will likely come at a significant cost, both in terms of increased piece cost and capital investment.

Moderate efficiency improvements may be possible in current engines by means of friction reduction, reduced weight, variable cam timing and improved fuel and spark control. Major improvements will likely require significant design changes such as the use of direct injection or hybrid powertrains.

Downsizing offers significant potential for fuel economy improvement, but will not likely be accepted in the marketplace. Effective downsizing can be accomplished rapidly through a change in vehicle model mix. Without a significant financial incentive directed at smaller vehicles, a significant model mix shift is not likely to occur. A large increase in fuel prices could cause such a

shift, but such an increase is not forecast.

Vehicle weight reduction can occur through the use of higher cost lightweight materials such as aluminum and magnesium, or by design efficiency improvements that will result in the use of less material.

It is important to note the "other responses" and "comments." These may contain special insight on emerging technologies that could significantly impact the fuel economy factor.

TECH-7. How much weight reduction and downsizing would be required to meet a passenger car CAFE standard of 30 and 35 mpg by 2007? Please use the optimal combination considering cost, vehicle packaging, etc.

	Median Response		Interquartile Range	
Effects of Increased CAFE Standards	**30 mpg**	**35 mpg**	**30 mpg**	**35 mpg**
Percentage weight reduction without downsizing	14%	20%	10/20%	15/30%
Percentage downsizing	10	20	5/20	10/30

Selected edited comments

- Based on a 6-8 percent fuel economy improvement for a 20 percent weight reduction. Ten percent size reduction is approximately equal to the difference between midsized and compact vehicles.
- Gains listed above will be offset by demand for higher performance, increased electrical loading due to proliferation of convenience features, increased mass due to safety regulations, and efficiency loss due to exhaust after treatment for emissions and noise. Net impact is little or no change in fleet fuel economy.
- Gains through weight and downsizing will quickly reach the point of being unrealistic alternatives to gain fuel economy.
- I arrived at a number by saying the average new car program downsized by 500 lbs. and 10 percent in size. I'm not even sure downsizing is a viable solution today; you still have to sell the things to someone.
- I assume downsizing equates to reduction in rolling loss, engine loss, aero loss, and the use of smaller displacement engines.
- I doubt the market will accept too much downsizing. Weight reduction will be constrained by cost, content, and "performance" considerations. Most likely the majority of the required fuel-economy gains to achieve a 30/35 mpg CAFE can, and will, come from improved powertrains.
- I see manufacturers working hard to abolish CAFE to let free market forces work for fuel prices and vehicle fuel economy.
- My answer assumes that the only change is mass and downsizing.
- Targets are not achievable by any of these options alone.
- This is based on the assumption that if CAFE is mandated the product mix will change to safe commuter/family vehicles—and the demographics and the material supply and cost trends do not change appreciably from the present.
- This will be difficult to accomplish through either approach while keeping the customer happy with cost/function.
- You get about a 6 percent improvement in fuel for every 10 percent of vehicle weight you take out.

Discussion

Panelists forecast that a 14 percent weight and a 10 percent size reduction would be required to meet a CAFE standard of 30 mpg. Weight and size reductions of 20 percent would be required to meet a CAFE standard of 35 mpg.

Manufacturer/supplier comparison

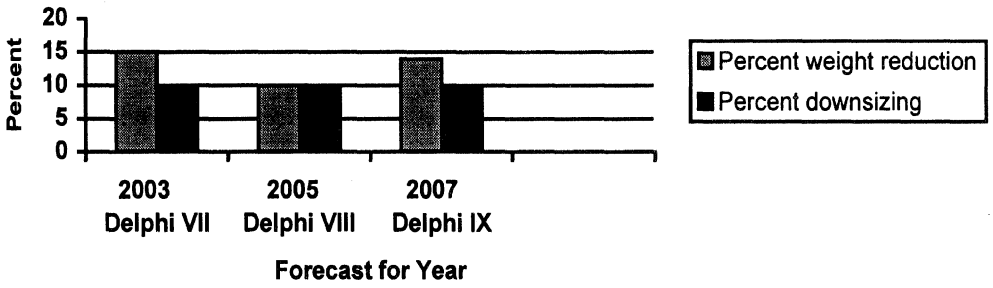
There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was first asked in the same format in the 1994 Delphi VII survey. Comparisons of estimates are summarized below.

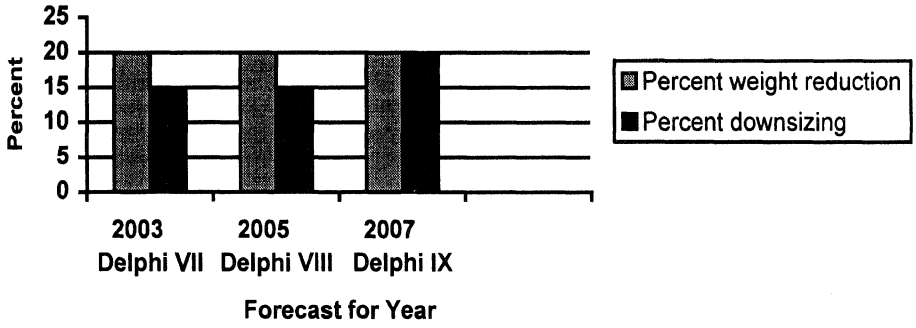
Effects of Increased CAFE standards	Delphi VII for 2003		Delphi VIII for 2005		Delphi IX for 2007	
	30 mpg	35 mpg	30 mpg	35 mpg	30 mpg	35 mpg
Percent weight reduction	15%	20%	10%	20%	14%	20%
Percent downsizing	10	15	10	15	10	20

Percent Weight and Size Reduction to Meet 30 mpg CAFE



Panelists for the past three forecasts are in general agreement, with the exception of the Delphi VIII forecast for weight reduction for 2005.

Percent Weight and Size Reduction to Meet 35 mpg CAFE



Panelists for the past three forecasts are in general agreement, with the exception of the Delphi IX forecast for downsizing for 2007.

Strategic considerations

Based on the forecast in Tech-3 for CAFE of 32 mpg for passenger cars for the year 2007,

panelists would project required weight reduction and downsizing of approximately 17 percent and 14 percent respectively. These figures represent significant challenges to vehicle manufacturers. Weight reduction may carry a high cost if material substitutions are the primary means of attainment. Certainly some weight reduction may be obtained through design efficiencies, but some material substitution would likely be required. Some previous downsizing programs have been poorly received in the marketplace. It is likely that if fuel remains inexpensive, as is forecast, downsizing will be poorly received again by the customer.

Certainly other vehicle systems such as the engine, transmission and accessories will contribute to future fuel-economy improvements. It is likely, however, that a CAFE of 32 mpg will require some level of weight reduction and downsizing. Of course, there are powerful incentives to achieve the required performance at minimum cost without compromising customer attributes. This would suggest downsizing would almost be a "last resort" tool and more efficient powertrains a preferred approach, assuming that the cost would not be excessive. In fact, the results of TECH-6 suggest that an engine efficiency improvement of 10 percent or 2.8 mpg would go a long way towards achieving a 32 mpg goal.

The fact that customers are increasingly choosing sport utility vehicles and minivans over passenger cars is an indication that they want larger vehicles, not smaller.

TECH-8. How much additional cost per vehicle, in current dollars, would a manufacturer be willing to add to a typical midsize passenger car to improve fuel economy by one (1) mile per gallon? This cost may be added for a new device, alternate material, revised material, improved technology, etc. Assume CAFE requirements at 27.5 mpg in 2002 and 30 and 35 in 2007.

	Median Response			
Vehicle Type	**1996 Current Value CAFE = 27.5 mpg**	**2002 CAFE = 27.5 mpg**	**2007 CAFE = 30 mpg**	**2007 CAFE = 35 mpg**
Passenger car	$25	$50	$100	$125
	Interquartile Range			
Vehicle Type	**1996 Current Value CAFE = 27.5 mpg**	**2002 CAFE = 27.5 mpg**	**2007 CAFE = 30 mpg**	**2007 CAFE = 35 mpg**
Passenger car	$10/50	$24/65	$50/120	$88/200

Selected edited comments

- A manufacturer is willing to increase prices only when the customer perceives the increase to be a value. In today's market, there is no value to a 1 mpg increase. Eventually there will be, due to artificial governmental pressures. Bureaucracies continue to expand whether they are needed or not.
- A manufacturer would not be "willing" to add to the cost of its vehicle to improve FE unless it were mandated by regulation or the added cost would give it a competitive advantage. The real driving force for FE improvement should come from competition in the marketplace rather than from the government. The most effective potential tool for decreases in energy consumption and, incidentally, emissions reduction, is a hefty fuel (e.g., gasoline or carbon) tax. This is not politically acceptable in this country.
- Added cost tolerable only to the degree that it is offset by a regulatory penalty or anticipated loss in sales. (Net – zero dollars)
- An assumption must be made as to whether the manufacturer is above or below the CAFE limit. Additionally, assumptions must be made as to the cost of the penalty. These additional costs are based on the assumption that CAFE is not being met. The manufacturers would not pay any money to increase beyond CAFE unless it was possible to trade CAFE credits to justify the additional costs.
- As CAFE standards change and technology improves, it will be more and more difficult to increase economy by 1 mpg.
- CAFE equal to 35 mpg only makes sense if fuel prices are rising.
- Customers will continue to buy vehicles based on price and performance, not fuel economy, unless fuel prices increase significantly.
- Fuel economy improvements will be dictated by the federal government. Neither the vehicle manufacturer, nor the consumer, is interested in fuel economy gains if it means extra expense. Component suppliers to the manufacturers will be asked to absorb the majority of the expense.
- Fuel prices and potential CAFE penalties will significantly influence the "value-of-fuel-economy" equation.

- I assumed that the manufacturer's fleet already meets the CAFE standard, so that the 1 mpg increase is solely a customer benefit. This question also depends heavily on the price of fuel.
- It depends on the price of fuel and where manufacturing is relative to CAFE requirements.
- It depends on what happens with global warming treaties.
- It depends on where the manufacturer is relative to CAFE standard. This assumes that they're missing it and have run out of credits.
- It is price sensitivity, not cost sensitivity, that must be the focus for vehicle manufacturers. For the years 1996 – 1999, the sensitivity is very high as customers are not demanding increased fuel efficiency.
- It is very misleading to "assume" a CAFE of 35 mpg by 2007. This is not economically feasible to achieve given market demands in the U.S.
- It really depends how desperate a manufacturer is in meeting CAFE and what the punitive measures are for not achieving the CAFE standard.
- Manufacturers are doing things, such as aluminum engine blocks to upgrade engine lines, which increase economy. This is normal product cost. Electric motor power would be a product cost to increase fuel economy. Look for changes in SUVs.
- Manufacturers are not "willing" to spend more beyond the CAFE requirements.
- Motor companies will not pay for additional fuel economy unless forced to by legislation or consumer demand. Unless the price of fuel rises dramatically, there will not be consumer pressure. If the better fuel economy can be had for little or no extra cost (e.g., technical improvements to design), then improvements will be incorporated.
- New technology will be expensive but in some cases, the manufacturers will be required to absorb the initial costs, due to government mandates (EV) or market pressures. Fuel economy is still not a significant purchase factor for most consumers.
- Not meeting CAFE becomes very expensive. As a result, manufacturers would be willing to spend money on premium materials and technologies. These costs would not easily be passed to consumers.
- OEMs will be driven by government regulations (CAFE: SUVs and minivans reclassified as passenger cars; revised emissions standards) while customer choice will be influenced by fuel price, assuming vehicle prices are stable relative to their "size."
- People/customers are cost driven. If fuel economy drives up vehicle cost, the people will revolt and elect officials who will repeal fuel-economy regulations. World market price for energy is the only driver for fuel economy. Vehicle manufacturers will give the customers what they want first and what the government mandates second. OEMs will win this battle.
- Since customers do not see any real value in fuel economy but are very concerned about affordability, there can be no increase in vehicle price for higher fuel efficiency. This means that the manufacturers cannot allow or accept any increase in price.
- Technology will dictate these costs. Each of these costs will have to be offset to provide a zero net effect on the vehicle cost.
- Technology will initially drive the price up for increased fuel efficiency, but since the end item consumer expects it for nothing, OEMs will drive cost out elsewhere so the net increase to the platform is $0.
- The cost OEMs are willing to pay will depend on the fines the government will enforce as a reason for noncompliance.

- The key driver is re-education as the customer does not reward or recognize fuel efficiency as a benefit worth increased cost. The answer: Assume a "carbon tax" penalty.
- The manufacturer has no choice. Technology dictates what the cost will be, not the manufacturer. Reaching 35 mpg will require prohibitive cost increases, vehicle downsizing, or loss of performance.
- The manufacturer is, almost by definition, not willing to add a single penny to the cost of a car. However, the regulations will force him to do it —whether he likes it or not. The key question is to what extent he will be able to pass these cost increases on to the consumer in the form of higher car prices. Given the superior fuel economy of Japanese cars, increasing car prices might be difficult for U.S. car manufacturers (except for those market segments where U.S. cars are perceived as clearly superior and thus enjoy a quasi-monopoly situation, i.e., primarily pickup trucks and sport utilities/vans.
- The real answer is the customers won't pay for better fuel economy, if left to their own devices, unless the price of fuel increases dramatically. The laws would have to force OEMs to spend the money and raise the prices.
- The underlying assumptions are that 1) the product mix does not change appreciably (and the popularity of the "heavier" class vehicles does not wane); 2) at some future date the SUV will be reclassified as a passenger vehicle/car rather than a light truck; 3) with caveats to 2, it will become extremely difficult and more costly to achieve 30-31 mpg and 35-36 mpg relative to 27.5 - 28.5 mpg.
- The value equation is bounded on the upper end by potential CAFE fines and vehicle life-cycle fuel cost savings (fuel price x gallons saved). On the lower end, it's bounded by the market's willingness to pay more (constrained/sometimes "zero"). The likely solution is somewhere between these extremes.
- This is not as simple a question as you portray it. The manufacturer needs to be cost-competitive yet meet the legislation. So if it could be done for zero dollars, that's the best solution. Also, it depends on how close one is to a certain inertia weight class, if you are close to a gas guzzler, etc.
- This really depends on each manufacturer's situation relative to fleet average fuel economy.
- This theory should include and consider different types of powertrains, such as hybrid systems (i.e., gasoline and EV). The definition of mileage calculation is not yet determined.
- To meet the 35 mpg CAFE would require a massive effort and a large change of customer acceptance (i.e., smaller vehicles, smaller engines.) It would also require a large mix of hybrid vehicles which are currently unproven.

Discussion

Panelists estimate that vehicle manufacturers are willing to pay $25 per vehicle currently to improve fuel economy by one mile per gallon. They forecast that this will increase to $125 per vehicle by 2007 if CAFE standards increase to 35 mpg.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Comparison of forecast: MAT-19

There is a statistically significant difference in responses between technology and materials

panelists. Mean responses for the two panels are summarized in the following table.

Mean Value of One Mile Per Gallon - $					
2002 CAFE =27.5 mpg		2007 CAFE =30 mpg		2007 CAFE =35 mpg	
TECH	MAT	TECH	MAT	TECH	MAT
$47	$17	$93	$46	$161	$82

Technology panelists forecast a much higher value placed on saving one mile per gallon than materials panelists for all scenarios. It should be noted, however, that the interquartile range is high for all parts of this question for the technology and materials panels, indicating uncertainty or differences of opinion.

Trend from previous Delphi surveys

This question was first asked in the 1996 Delphi VIII survey. Results of that survey are compared to those of the current survey in the following table.

1998 Delphi IX	1997 Current Value CAFE = 27.5 mpg	2002 CAFE = 27.5 mpg	2007 CAFE = 30 mpg	2007 CAFE = 35 mpg
	$25	$50	$100	$125
1996 Delphi VIII	**1995 Current Value CAFE = 27.5 mpg**	**2000 CAFE = 27.5 mpg**	**2005 CAFE = 30 mpg**	**2005 CAFE = 35 mpg**
	$50	$69	$120	$200

Panelists in the Delphi IX survey estimated a lower current value that manufacturers would be willing to pay than panelists of the previous survey. Likewise, the forecast for future years is lower in the current survey. It should be noted that the interquartile range is large in both surveys, indicating uncertainty or differences in approach between manufacturers.

Strategic considerations

Panelists estimate that manufacturers are currently willing to add vehicle cost to improve fuel economy. They forecast that this amount will increase in the future if CAFE is increased.

Improving fuel economy offers a marketing advantage to the manufacturer, although the magnitude appears low in the current market. Manufacturers are also interested in improving fuel economy in order to comply with CAFE requirements. This is of particular importance as consumers move to larger, less fuel-efficient vehicles.

A number of comments refer to the fact that the amount a manufacturer is willing to pay is largely a function of where that manufacturer stands with regard to CAFE standards. This is likely true between Japanese manufacturers that easily meet CAFE standards and domestic manufacturers that continually struggle to meet CAFE because of high sales of large vehicles. The issue is more complex with regard to individual models within one manufacturer. The implication is that the manufacturer adds cost if required to bring that model into CAFE target compliance. In reality, the process is not that simple. During the development process, weight is often added to solve durability problems. By the time the total vehicle weight is known with a high degree of certainty, it is too late to add weight savings features or change to lightweight materials.

Another complicating factor is the fact that many components are used across several vehicle

lines. The move from cast iron to aluminum for engine cylinder heads and blocks is an example of a willingness on the part of manufacturers to add cost to a component that is used across vehicle lines. In this case, the decision is not based on whether or not a specific model is near a weight-class limit, but rather on the basis that all vehicle models using the engine will be reduced in weight. Some will decrease by a test weight class, whereas others will not. This type of analysis must be applied to other components throughout the vehicle.

The comments in this question are astute and thoughtful. They certainly suggest that this is a highly complex issue with many variables. We have asked the question to help understand this complexity.

Considering the industry/government Partnership for a New Generation of Vehicles (PNGV) program, please respond to the following questions. (TECH 9-12)

TECH-9. What will be the likely average combined city/highway fuel economy mpg (EPA test procedures) in production family size (five passenger) cars in 2010 and 2020? Assume price, safety, convenience, range, performance, etc. on parity with today's vehicles.

	Median Response	Interquartile Range
Year	Average Fuel Economy	Average Fuel Economy
2010	35 mpg	30/35 mpg
2020	40 mpg	35/42 mpg

Selected edited comments

- A significant driving force will be the pressure worldwide to reduce emissions of greenhouse gases (GHG). The limitation in PNGV on price will be a serious handicap. Probably, the most viable option today is a significantly improved diesel engine, but it will face serious opposition from environmental groups/regulators because it is considered "dirty" technology, although it will meet the applicable emission standards. Hybrid electric vehicles seem to have great potential, but still need a lot of development and will have significantly higher cost. Fuel cells may be the eventual technology of choice, but probably not before 2020.
- All of the PNGV Goal 3 assumptions cannot be met. The effect of PNGV on production vehicles can only be incrementally implemented with the result being no different than those expected through PNGV Goal 2. PNGV is the best program going in our industry in that government and industry are working together. Whatever level is achieved, it will be accepted because both factions have been a party to the effect.
- As long as price, safety, etc., must be on a par with today's vehicles then only petroleum technology is feasible and no change can occur. Electric vehicles, even hybrid electrics, have significant negative cost/benefit ratios. Customers won't buy it.
- Assumptions: family size refers to Camry/Taurus/Accord class and same convenience/safety and cost/average income basis (there are five-passenger cars now that will give over 35 mpg, however). In spite of the professed "lofty" goals and claims, this author shares the skepticism of many who are close to the PNGV program. A "cost-effective" 70 mpg or even 40 mpg family car is unlikely without major technology breakthroughs.
- Count on materials improvement; also, education of design engineers in the use of materials; better structural optimization with the use of CAD; improved math modeling of systems; and the aforementioned use of smart controls for smoother transitions in operating modes.
- Diesel hybrids should make above possible.
- Diesels will be the most significant factor, especially in SUVs and trucks, but also some penetration in cars. PNGV "solutions" appear to be generally cost-prohibitive.
- Direct injection for both gasoline and diesel engines will be common.
- Even achieving above numbers will be difficult if fuel prices remain stable.
- Fuel cells (gasoline or methanol-fueled) will play a large role by 2020.

- Hybrids will be common in fleets by 2020.
- I believe that technology improvements, coupled with legislation and foreign pressures, will dictate the achievement of improved fuel economy.
- I don't believe we'll have parity in performance.
- I don't have a great deal of confidence that the Partnership will have a significant impact on fuel economy. The results to date reflect this. By excluding companies which possess some of the best technology, they are significantly limiting their potential.
- If price, safety, and convenience will be on a parity with today's vehicles, there will be little change in fuel economy. Alternatives will be very expensive to develop and manufacturers will not absorb the costs. I don't feel that government/industry partnerships will work in harmony together. Results, if any, will be below expectations.
- If price, safety, convenience, etc. are the same as today's vehicles, then the fuel economy will change very little compared to today's vehicles. The only PNGV programs reported to date are extremely cost prohibitive.
- Improved fuel economy through weight savings made possible through the use of improved materials remains the most likely option.
- It heavily depends on the CAFE standard.
- It is unlikely that there will be any significant increase in fuel economy unless driven by legislation.
- It will be whatever the CAFE laws require, as that is the only driving factor for improved fuel efficiency in the USA.
- It would depend on the diesel emission standard and the definition of alternative fuel vehicles. Currently, bifuel (gasoline and CNG) vehicles have a great advantage when calculating fuel economy.
- Keeping the price comparable is keeping further gains from occurring.
- Major emphasis on alternative fuel may be an option.
- Mass reduction and engine efficiency should be the focus elements. Items like the elimination of spare tires are excellent examples (no-flat OEM tires).
- My projection assumes that customers have gotten used to repackaged, downsized, but more space- efficient, lighter vehicles. Powertrains remain petroleum-based.
- PNGV is another effort by the Big Three to "hoodwink" the U.S. consumer and the U.S. government that they are truly concerned about improving the environment. Bring in some competition and see how fast they can REALLY change. If the U.S. government truly wants this program to be successful, remove the veil of "made in America" and make this a Partnership for a New GLOBAL Vehicle.
- PNGV technology is too expensive. Automobiles are already reaching the limits of affordability.
- Price/affordability considerations will play against political (CAFE) and environmental pressures to influence passenger-car fuel economy. Potential impacts on the car/truck vehicle mix are not yet fully resolved.
- Price/affordability is likely to be the primary constraint in this equation.
- Probably diesel, or natural gas engines will prevail.
- The public won't buy PNGV vehicles until proven.

- There will be an increased pressure to develop diesel engines that are equivalent to gasoline engines in performance and drivability.
- There will be individual models that will get higher fuel economy, but it will take at least a decade for our customers to get comfortable with the new technologies and for the industry to roll them out across the entire group of "family sedans". Thus, the average will be closer to the numbers above than it will be to the 80 mpg being quoted for the PNGV.
- This assumes a drive exists for massive retooling for lower weight/higher efficiency.
- This is meaningless without stating a CAFE standard for those years.
- This will not be driven by PNGV but rather by the legislation for fuel economy. Also, it will be driven by the need for cleaner air worldwide, depletion of oil reserves, etc. The major technology is weight reduction, not P/T efficiency.
- We must rethink the concept of this five-passenger vehicle.
- With gasoline prices rising rapidly, there will be increasing pressure on the manufacturers to increase fuel economy.
- You can not change customer demand for big, powerful vehicles.

Discussion

Panelists forecast that the average combined city/highway fuel economy in production family-sized passenger cars will be 35 mpg in 2010 and 40 mpg in 2020. This is well below the PNGV goal of 80 mpg.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

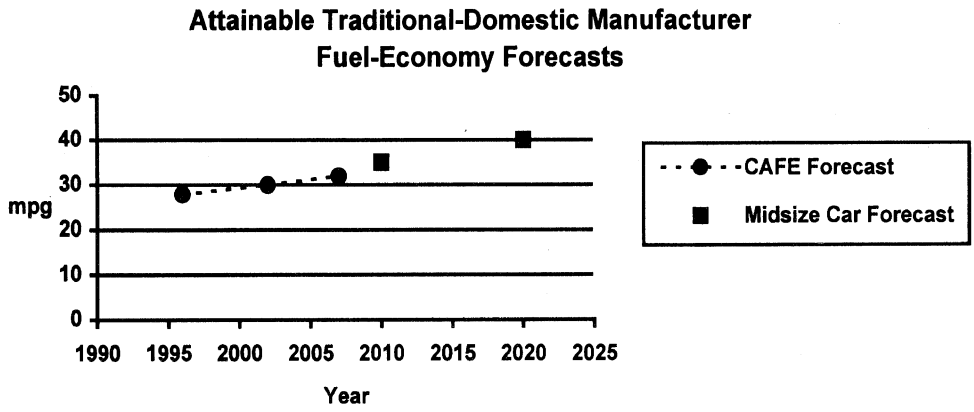
This question was first asked in the 1994 Delphi VII survey. Results of the current survey are compared to those of the two previous surveys in the following table.

Survey	mpg forecast for 2010	mpg forecast for 2020
1998 Delphi IX	35	40
1996 Delphi VIII	35	40
1994 Delphi VII	37.5	45

Forecasts for the current survey are in agreement with those of the previous survey (Delphi VIII.) Forecasts were somewhat higher in the 1994 Delphi VII survey, however.

Strategic considerations

The responses to this question are compared in the following graph to those of TECH-5, which forecast fuel economy to 2007.



The results of this question are in line with those of TECH-5. It is likely that the PNGV program will contribute significantly to the increased fuel economy through the year 2020. The forecast results are far short of the PNGV goal of 80 mph, however.

Again, as in the prior question, the individual comments are worth noting. Of course, attainable levels are highly dependent on inventions not yet made. In fact, invention is very difficult to forecast but will certainly be necessary if the values suggested by the panel are to be achieved.

The real issues regarding future fuel economy are fuel price and availability, government policy and economics. Even today, the 80 mpg vehicle is technically feasible. However, the economic gap between technical feasibility and commercial reality is enormous.

TECH-10. Can the PNGV goal of 80 mpg be achieved in a production family-sized (five passenger) car? If yes, by what year?

		Median Response	Interquartile Range
YES	NO	If yes, by what year?	If yes, by what year?
54%	46%	Year: 2015	Year: 2010/2025

Selected edited comments

- "Cost-effective" is defined by customer cost (purchase price + insurance + maintenance costs) compared to average per capita income in constant dollars. Also, the breakthroughs needed in technology are unlikely considering the progress to date. Although the author does not go as far as to characterize the PNGV as a scientist/engineer/bureaucrat welfare program as many cynics in the industry call it, he believes that most of the technology breakthroughs, if any, will come from entities outside the PNGV program.
- Cannot achieve 80 mpg in the foreseeable future without breakthroughs in basic technology. A CAFE standard at that level would not be politically sustainable because of severe motorist backlash.
- Current safety needs as perceived by the customer will not allow the meeting of such a high standard. Possibly the standards could be met in Europe where the perceived safety need is not noted.
- Eighty mpg cannot be attained without compromising the cost, size and safety objectives.
- Eighty mpg is achievable by 2020, but is highly unlikely. (1) The cost could be prohibitive and (2) other technology such as the electric car with low-cost fusion powerplant may make the combustion engine obsolete.
- Eighty mpg is technically achievable. However, achieving 80 mpg affordably in a reasonably "balanced" vehicle requires many enablers yet to be invented/developed. Lack of incentive (i.e., cheap fuel readily available) and a high expected infrastructure cost to achieve the objective results in a very long timeline, i.e., 25 to 50 years.
- I believe that will depend more on the development of Smart Traffic Control where traffic flow is better controlled than on the vehicle itself. Traffic jams will have to be eliminated to permit a better base drive mode for the fuel-economy test.
- If it does happen, it will be at the expense of current-level comfort, size, and performance. Eighty mpg vehicles will not satisfy today's consumer expectations and will not be purchased unless taxation or legislation forces consumers to make high-mpg vehicles desirable.
- It can be achieved perhaps, but could it be produced as an actual consumer product that meets safety, cost, and consumer requirements? NO.
- It will take until 2010 to get the cost of the new technology down to the cost targets that have been set for the PNGV. The technology will meet the fuel-economy goal in the 2004 target year, but only the federal government will be able to afford the cars.
- It would be much too expensive to be sold.
- It's going to cost a bunch more.
- Not at constant economics—materials changes will never "zero-out."
- Not in our lifetime.

- Not with current technology. However, hybrid vehicles show the most promise for a marketable solution.
- Not with today's performance, size, and at today's selling prices. However, I'm not sure what might be attained with fuel-cell technology.
- Price and performance assumptions are too restrictive to achieve the 80 mpg goal.
- Small diesels are almost there.
- The cost would be far too high to be realistic.
- The issue, as always, will be cost.
- The key word is "production." Unless heavily subsidized, an 80 mpg automobile is not practical.
- The new Audi A will be a five-passenger vehicle with 79 mpg (European standards) and diesel-powered (dirty). Eighty mpg will need all of the technology tricks and will be very expensive.
- The PNGV 80 mpg goal is a CAFE number. Average city and highway economy, using new RDP-1 driving schedules of 80 mpg, will be achieved when oil is scarce and $10/gallon gasoline is all that is available. Electric vehicles will never be more than a niche car, never exceeding 1 percent of production. If government funds stop, so will PNGV. There is no incentive.
- The vehicle will be possible, but at twice the current price (in today's dollars).
- This can only happen at a significant cost increase and loss of customer function.
- This cannot be attained without *major* cost increases and performance reduction.
- This requires an alternate power source such as an inertia-based flywheel engine.
- This requires that the aluminum and composites people to come to the party. Currently this is a chicken and egg problem. Also, this requires the fuel manufacturers to come to the party. Remember, today's engine is highly optimized for 91 octane fuel.
- This will require a hybrid drive system and/or a fuel cell for full-size cars.
- Yes, in a hybrid vehicle.
- Yes, in a hybrid vehicle with heavy composite structure.

Discussion

The majority of respondents (54 percent) viewed 80 mpg as an attainable goal in the foreseeable future for a production five-passenger family car. The median year for accomplishment of this goal was 2015. Many respondents (46 percent), however, did not view the goal as attainable.

Manufacturer/supplier comparison

There is no statistically significant difference between manufacturers and suppliers.

Trend from previous Delphi surveys

In the previous two surveys, the fuel-economy goal was stated as 87 mpg. The results, therefore, are not directly comparable. In the Delphi VIII survey, 65 percent responded that the goal of 87 mpg was attainable.

Strategic considerations

The Partnership for a New Generation of Vehicles may create breakthrough technology for

improvements in fuel economy. The most significant challenge, however, may be to provide this technology at a cost that consumers can afford. Many panelists in this survey express doubts that the goals can be attained. It is likely, however, that the PNGV will accelerate the pace of development of high fuel-economy vehicles.

There are many concepts under development that can provide building blocks for the 80 mpg vehicle. These include efforts to reduce vehicle weight, aerodynamic drag, and rolling resistance, as well as improvements to current powertrains and development of new ones. More advanced concepts such as ultra capacitors, fuel cells and flywheels may prove feasible. Advances in battery technology may move forward the large-scale sale of electric or hybrid vehicles. Furthermore, developments in the control of exhaust emissions from diesel engines may allow the use of these more efficient engines in passenger cars.

While a combination of the above items (or others not noted) may provide the key to the 80 mpg vehicle, the attainment of this level of fuel economy while maintaining function and affordability remains a formidable challenge.

The comment regarding the fact that the PNGV effort is essentially a North American program may be particularly pertinent. It may be wise to consider expanding the effort to include international participants.

TECH-11. What factors will make the greatest contribution to increased fuel economy in the PNGV program in the next quarter century?

Scale: 1 = extremely significant 3 = somewhat significant 5 = not at all significant

Factors	Mean Response
Weight reduction	1.8
Engine improvements	1.9
Hybrid powertrain	1.9
Electronic controls	2.2
Energy storage (flywheel, etc.)	2.5
Transmissions	2.6
Aerodynamics	2.9
Tire rolling resistance	3.1
Accessory drive	3.2

Other Responses:

Hybrid battery technology - 1

New diesels - 1

Regenerative braking - 1

Smart engine control; smart drive mode control and smart highway traffic control - 1

Wheel bearings and brake drag - 3

Selected edited comments

- Better modeling and better control of everything from in-process tolerances, to engine demand, to vehicle drive mode, to traffic control will be improved by Smart Control Devices. Smooth and controlled operations will be the byword.
- I do not foresee any radical changes in automotive technology.
- I equate the transmission as part of the hybrid powertrain.
- Power-to-weight ratio advancement is an important factor.
- The most promising combination is a lightweight diesel engine with energy storage.
- The most promising technologies (however mundane) are: (1) accessory drive to include starter/alternator/engine flywheel; (2) rapid-response electronic controls; (3) engine improvements, e.g., 2-stroke diesel; (4) transmissions - 5/6 speed automatics and CVT; and, of course, (5) vehicle/powertrain weight reductions.
- The significance of transmissions depends greatly on the other factors, such as the type of hybrid powertrain.
- The significance of transmissions depends greatly on the other factors, such as the type of hybrid powertrain.
- Weight reduction is still the key—new materials are the enabler.

- Weight reduction is the major enabler. Also, fuels and catalyst technology will contribute.

Discussion

Panelists forecast that weight reduction, engine improvements, hybrid engines, and electronic controls will play the greatest role in attainment of the 80 mpg vehicle.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was first asked in the same format in the 1996 Delphi VIII forecast. Results of the two forecasts are compared below.

Factors	Delphi VIII Mean Response	Delphi IX Mean Response
Weight reduction	1.8	1.6
Engine improvements	1.9	1.8
Hybrid powertrain	1.9	-
Electronic controls	2.2	2.2
Energy storage	2.5	-
Transmissions	2.6	-
Aerodynamics	2.9	2.8
Tire rolling resistance	3.1	2.8
Accessory drive	3.2	3.1

Weight reduction and engine improvements were the most significant expected contributors to the goal of an 80 mpg family vehicle in the current and past survey. Responses for other factors are similar for the two forecasts.

Strategic considerations

Improvements in many areas of the vehicle will be required to attain a goal of 80 mpg. Panelists forecast that all of the factors noted will provide at least a somewhat significant contribution to increased fuel economy. They forecast that the greatest contributions will come from weight reduction, engine improvements and hybrid powertrains, however.

Weight reduction may come from lightweight materials such as aluminum, magnesium and composite materials. Weight reduction may also be realized through more efficient use of current materials. Increased use of computer modeling will allow engineers to design components with a reduction in the amount of material used.

Engine improvements may come through the evolution of current systems or revolutionary changes such as direct injection diesel and gasoline engines, fuel cells, hybrid or electric power sources.

TECH-12. Please rate your expectations for the impact of PNGV on the following performance dimensions in the next quarter century.

Scale: 1 = very high expectations 5 = very low expectations

Performance Dimensions	Mean Rating
Fuel economy improvements	1.8
Materials advances	1.8
Emissions control advances	2.5
Competitiveness with foreign manufacturers	3.0
Production process improvements	3.0
Comfort/convenience improvements	3.8
Cost reduction	3.8

Selected edited comments

- I am skeptical as to the major "fuel cell" powerplant breakthroughs. Indeed if energy-storage and energy-conversion (e.g., fuel cells, etc.) breakthroughs do materialize, they should result in a #1 rating.
- I doubt that PNGV will survive well into the next quarter century.
- I expect that PNGV will have to sacrifice comfort/convenience and dramatically increase cost in order to achieve the fuel-economy target.

Discussion

Panelists have the greatest expectations for the PNGV program in the areas of fuel-economy improvements and material advances.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of comfort and convenience improvements. For this part of the question, the manufacturers' mean response is 4.1 compared to 3.5 for suppliers.

Trend from previous Delphi surveys

This question was asked in this format for the first time in the 1996 Delphi VIII forecast. A comparison of the results of the two forecasts is shown in the following table.

Performance Dimensions	Delphi VIII Mean Response	Delphi IX Mean Response
Fuel economy improvements	1.8	2.0
Materials advances	1.8	2.0
Emissions control advances	2.5	2.6
Competitiveness with foreign manufacturers	3.0	2.9
Production process improvements	3.0	2.9
Comfort/convenience improvements	3.8	3.6
Cost reduction	3.8	3.2

Results for the two forecasts are similar, with a somewhat greater expectation for cost reduction in the current forecast.

Strategic considerations

Panelists express at least moderate expectations from the PNGV for all of the performance dimensions noted. The greatest expectations, however, are in the areas of fuel economy improvements and materials advances.

Cooperation between government and industry has provided a competitive advantage for vehicle manufacturers in other parts of the world, notably Japan. The PNGV offers an opportunity for U.S. industry and government to advance the state of the art of vehicles in the important areas of fuel economy, materials, and emission controls in relation to foreign competitors. This is certainly to the benefit of both industry and government. Jobs and corporate profits are at stake in the global vehicle market. Programs such as PNGV can assist in maximizing the utilization of resources to secure these jobs and corporate profits.

Still, with globalization of the industry, a natural question arises. Is it in the best interest of the industry and its customers to exclude foreign participation in the PNGV program?

TECH-13. What percentage of North American-produced passenger cars and light trucks (including fleets) will use each of the following fuels or power plants in 2002 and 2007?

		Median Response		Interquartile Range	
Alternate Fuels Passenger Cars	**1996***	**2002**	**2007**	**2002**	**2007**
Alcohol or alcohol/gasoline (>10 percent alcohol; includes flex fuel or variable fuel)	<1%	2%	5%	1/5%	2/10%
Diesel	0	2	5	1/5	1/10
Electric	0	1	2	1/2	1/5
Hybrid-electric/combustion engine		1	5	1/3	2/10
Natural gas	0	1	2	0/2	1/5
Propane	0	1	1	0/1	0/2
Light Trucks	**1996***	**2002**	**2007**	**2002**	**2007**
Alcohol or alcohol/gasoline (>10 percent alcohol; includes flex fuel or variable fuel)	<1%	2%	3%	1/5%	1/10%
Diesel	3.8	5	10	5/10	8/20
Electric	0	0	1	0/1	0/3
Hybrid-electric/combustion engine	0	1	1	0/2	0/5
Natural gas	0	1	3	1/2	1/7
Propane	0	1	1	0/2	0/4

***Source:** Ward's Automotive Reports, Feb. 3 and 24, 1997, and OSAT estimates. Rates or 1996 are based on production in U.S., Canada, and Mexico for the U.S. market.

Selected edited comments

- EV mandates, if enforced, will impact projections. Hybrids have much more potential and will better meet consumer demands for range and flexibility. Regional differences will become more significant due to available fuel sources and environmental conditions.
- Gasoline and gasoline engines are low cost and low emissions. I see no reason for a substantial shift away from this technology for the foreseeable future. Alcohol will make some inroads because of bureaucratic pressure to help agriculture. Electric vehicles could make more inroads than I project if a major breakthrough in battery technology occurs.
- High-speed, direct-injection diesels will prove themselves in Europe and will start showing up in North American passenger cars.
- I believe that by 2007 we will see a few passenger cars with fuel cells on the road.
- It all depends on availability!

Discussion

Gasoline is forecast to remain the dominant fuel for the next decade. Diesel engines are forecast in 10 percent of light trucks by 2007. Other fuels or power plants are forecast in 5 percent of vehicles or less.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Comparison of forecast: MAT-5

There is a statistically significant difference in mean responses between technology and materials panelists for the alternate fuels in passenger cars and light trucks in the years shown in the following table.

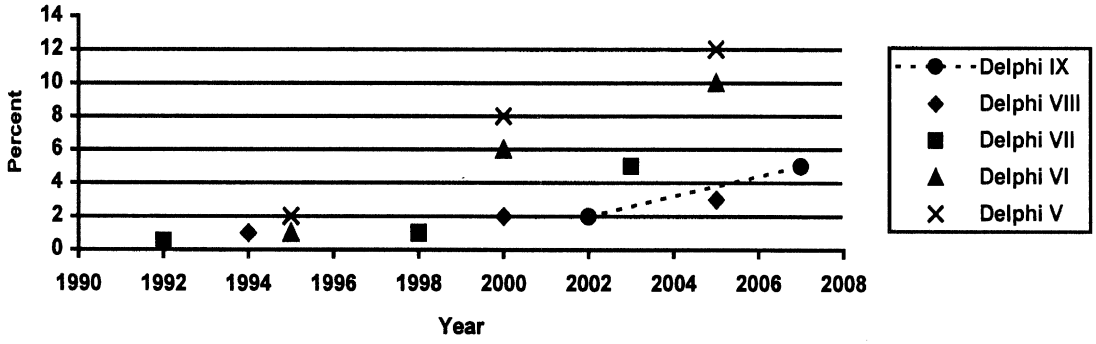
Alternate Fuels - Percent				
	2002		2007	
	TECH	MAT	TECH	MAT
Passenger Car				
Diesel	4.2	1.6	7.8	4.3
Light Truck				
Diesel	6.5	5.0	15	9
Natural gas	2.3	1.0	4.4	2.3

Technology panelists forecast higher use of diesel in passenger cars and light trucks, and natural gas in light trucks, than materials panelists.

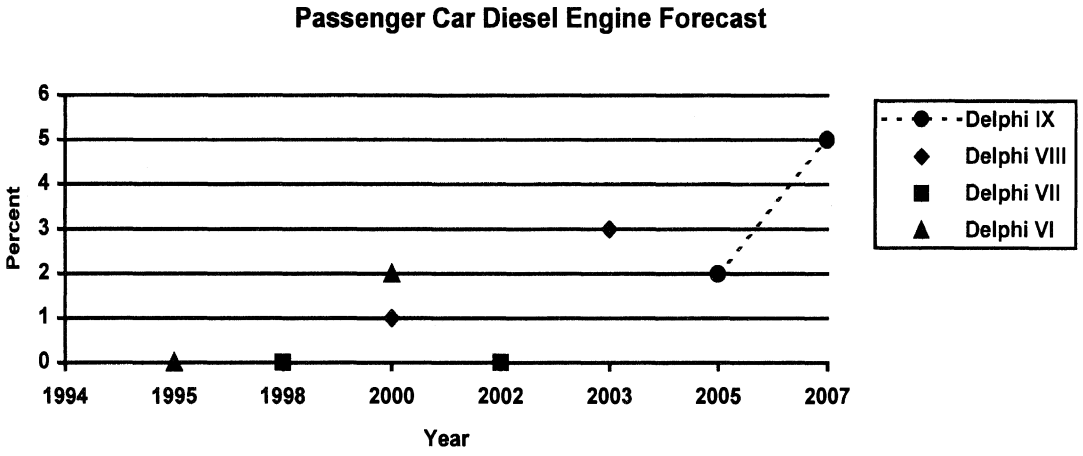
Trend from previous Delphi surveys

The forecast of 5 percent for alcohol or alcohol/gasoline fuels for passenger cars in 2007 is in line with the past two surveys, but is significantly below that of the 1989 Delphi V and 1992 Delphi VI surveys. This is shown in the following graph.

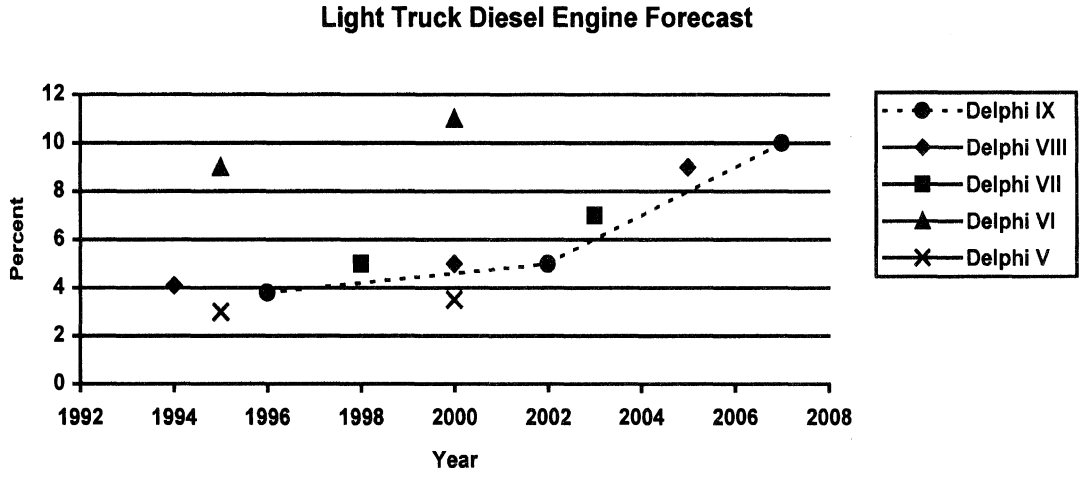
Passenger Car Alcohol or Alcohol/Gasoline Use Forecasts



The forecast for passenger-car diesel-engine penetration has increased with each of the past two surveys, as shown in the following graph.



The current forecast for diesel engines in light duty trucks is in line with previous forecasts with the exception of the 1992 Delphi VI forecast. The Delphi VI panelists forecast a higher penetration of diesel engines in light duty trucks, as shown in the following graph.



Forecasts for other fuels or power plants are similar in this and previous forecasts.

Strategic considerations

Current panelists forecast that there will be only limited use of alternate fuels or power plants in the next decade. Some alternate fuels or power plants offer some advantages over gasoline, but on balance, gasoline is forecast to be the fuel of choice for most consumers. Other alternatives have significant disadvantages when compared to gasoline in the areas of vehicle range, fuel cost, power plant cost, delivery infrastructure or safety.

Diesel engines offer a significant fuel-economy advantage over gasoline engines, but have disadvantages of high-engine cost, noise, odor and emissions control. Many panelists apparently believe that the problem of control of emissions from diesels will be resolved in the next decade, as the forecast is for increased use of diesel engines. The fuel-economy advantage of diesel engines is particularly attractive for light duty trucks. For this application some of the disadvantages such as noise and odor may not be viewed as troublesome.

Hybrid vehicles offer the potential for significant fuel-economy improvements. This is primarily

due to the fact that a small combustion engine running at a high load has a much higher efficiency than a larger engine running at a light load. Engines in current vehicles operate at a small fraction of their capacity during most driving situations. A small engine in a hybrid vehicle can run near a constant high load and rely on an electric motor to handle peak requirements. The 5 percent penetration expected for hybrids by 2007 is a particularly significant result in this forecast, suggesting this technology should be followed closely in the years just ahead.

Alcohol fuels could be manufactured from coal or biofeedstock, such as corn. Energy density is lower for alcohol than gasoline and the cost is higher than gasoline. There is an incentive in the corn-producing states to support the introduction of alcohol fuels.

Fuel cells were mentioned by one panelist as having some application in the next decade. These devices convert fuel to electricity directly at a very high efficiency. These devices have generally used a gaseous fuel such as hydrogen in the past and have been limited by the logistics of storing and transferring the gas to the vehicle. Work is in progress to use gasoline as the fuel for fuel cells and convert it to hydrogen in the vehicle. The cost of such a system is currently one of many challenges.

The extremely low lease rate of the GM EV-1 electric vehicle is an indication of the problem of selling a power plant that does not compare favorably with a gasoline engine. It also demonstrates the difficulty that automobile manufacturers would have in meeting mandated sales volumes of electric vehicles (as has been proposed in California and some northeastern states.) GM has stated that they will soon introduce a nickel-metal hydride battery that will double the range of the EV-1. This will significantly improve the practicality of this vehicle, but does not overcome other problems such as recharge time and infrastructure for recharging. The nickel-metal hydride battery is currently available in the Toyota and Honda electric vehicles.

There are benefits to the economy in reducing our dependence on gasoline, as we currently import approximately half of the fuel oil that is consumed. The use of coal to generate electricity or methanol could improve the balance of payments caused by imported oil. Our dependence on foreign countries for much of our energy supply also places us at risk in times of political turmoil.

Without a significant increase in the price of gasoline or a gasoline shortage, gasoline engines will remain the power plant of choice by most consumers. Only a political upheaval in the oil-supplying countries, a concerted move by legislators to increase the price of gasoline, or increases in CAFE requirements are likely to cause significant moves to alternate fuels or power plants in the next decade.

It should be kept in mind that knowledge of these technologies (as well as other technologies discussed in this report) are not uniform across the industry. One organization or small group may have a far more advanced understanding of a given technology than others. Hence median responses may not have great meaning; the forecasts of responses that really are at the leading edge may be beyond the quartile range and thus cast aside. Individual comments are particularly interesting in questions of this type.

TECH-14. What percent of electric or hybrid vehicles will utilize the following battery types in 2002 and 2007?

Types of Batteries	Median Response		Interquartile Range	
	2002	2007	2002	2007
Lead-acid	60%	35%	50/71%	20/50%
Lithium Ion	3	5	0/5	2/10
Lithium-polymer	4	10	1/5	5/15
Nickel-cadmium	2	2	0/5	0/5
Nickel-metal hydride	21	38	15/30	25/50

Other Responses:

Fuel cell – 2002: 0%; 2007: 10%

Nickel chloride – 2002: 5%; 2007: 5%

Other (not yet invented?) 13 responses

2002: Median response 13, lower quartile 1, upper quartile 24

2007: Median response 15, lower quartile 6, upper quartile 30

Zinc-Air – 2002: 5%; 2007: 15%

Zinc bromide – 2002: 0%; 2007: 10%

Selected edited comments

- A significant breakthrough in battery technology (energy density) is needed to make the pure electric vehicle a viable personal transportation option in large numbers. I do not believe this will happen by 2007.
- Conversion vehicles will continue to use some lead-acid but NMH will be the near-term workhorse.
- I am surprised that so many respondents feel that lead-acid will continue to be strong. Their limitations will severely hamper the expansion of EVs. Production capability of NMH batteries will also be a major factor.
- Lead-acid will prevail unless there is an outstanding breakthrough in a new battery technology.
- Nearly all batteries will be lead-acid.
- Range will dictate something better than lead acid.
- The cost versus energy/density versus durability battle is being waged. The outcome is far from certain, but lead-acid will remain "king" until then.
- The next three years will clarify this picture.
- There must be battery improvement to make hybrid/electric vehicles viable.
- There will be no EVs by 2007.

Discussion

Panelists forecast that lead-acid batteries will be used in most electric or hybrid vehicles through 2002 (60 percent), but nickel-metal hydride batteries will be the high-volume battery by 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers, with the exception of those shown in the following table.

Electric or Hybrid Vehicle Batteries				
	2002		2007	
Type of Battery	Mfr.	Supp.	Mfr.	Supp.
Lead-acid	56%	67%	31%	47%
Nickel-metal hydride	26	18	--	--

Suppliers forecast a higher use of lead-acid batteries in the future than manufacturers.

Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey. Results of the current survey are compared to those of the previous two surveys in the following table.

Forecast for year →	1998	2000	2002	2003	2005	2007
Survey →	1994 Delphi VII	1996 Delphi VIII	1998 Delphi IX	1994 Delphi VII	1996 Delphi VIII	1998 Delphi IX
Type of Battery						
Lead-acid	80%	80%	60%	50%	60%	35%
Lithium-ion	-	-	3	-	-	5
Lithium-polymer	0	0	4	5	10	10
Nickel-cadmium	5	6	2	5	10	2
Nickel-metal hydride	0	8	21	10	20	38

The trend is towards increased forecasts for nickel-metal hydride batteries, with some increased use of lithium-polymer.

Strategic considerations

Limited vehicle range remains a significant negative for electric vehicles. As a result, considerable research is being directed toward alternatives to the lead-acid battery. Manufacturers have announced production applications of nickel-metal hydride and lithium-polymer batteries. Cost remains a problem for both of these alternatives, however. It will be interesting to watch future developments with regard to these alternatives. Other alternatives may also appear in the future, as noted by a number of panelists.

It must be kept in mind that we know the fundamental potential of various battery types regarding energy and power density. Only a few hold significant promise, even if various technical and commercial problems can be resolved.

TECH-15. Considering vehicles with hybrid electric/combustion engine propulsion, what percent will utilize the following types of combustion engines in 2002 and 2007?

Combustion Engine used in Hybrid Vehicles				
Combustion Engine	Median Response		Interquartile Range	
	2002	2007	2002	2007
Spark ignition	75%	50%	50/90%	20/78%
Compression ignition, diesel	20	30	10/50	10/55
Stirling	0	0	0/1	0/5
Turbine	0	2	0/2	0/10

Selected edited comments

- Spark ignition could be a higher percentage if a breakthrough in lean NOx catalysts occurs which would bring direct injected spark-ignited engines to their full potential.
- Spark ignition will remain the workhorse.

Discussion

Panelists forecast that spark-ignition engines will be used in 75 percent and diesel engines in 20 percent of hybrid electric/combustion engine vehicles in 2002. The use of diesel engines is forecast to increase to 30 percent by 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was not asked in previous Delphi forecasts.

Strategic considerations

Automotive manufacturers have reported that they are working on a number of alternate combustion engines for use in hybrid vehicles. These include spark ignition (both conventional and direct injected), diesel, stirling, and gas turbines. Panelists forecast that spark-ignition engines will dominate initially, but diesel engines will increase in use by 2007. No significant use of stirling or turbine engines is forecast, in spite of the published work on these engines by automotive manufacturers.

There is a large interquartile range in responses for each of the engine types. This may be a result of uncertainty or different strategies by the various manufacturers.

The relatively low-fuel consumption of diesel engines makes this an attractive alternative. Emission controls of diesel engines remain a challenge, however.

It is early in the development phase of hybrid power plants. Engine choices may change as development progresses.

TECH-16. Please indicate your view of the trend in U.S. federal regulation and legislation over the short term (1998-2002) and long term (2003 to 2007). Also, please list any likely new areas of legislative and/or regulatory activity.

Scale: 1 = much more restrictive 3 = no change 5 = much less restrictive

	Mean Response	
Legislation/Regulatory Activity	**Short Term 1998-2002**	**Long Term 2003-2007**
Vehicle emission standards		
Passenger car	2.6	2.0
Light truck	2.4	2.0
Occupant restraint/interior safety		
Passenger car	2.4	2.2
Light truck	2.2	2.1
Vehicle integrity/crashworthiness		
Passenger car	2.4	2.1
Light truck	2.3	2.0
Alternate fuel/power source		
Passenger car	2.8	2.3
Light truck	2.9	2.4
Antitheft equipment		
Passenger car	3.0	2.9
Light truck	3.1	3.0
Regionalization of national standards		
Passenger car	2.9	2.9
Light truck	3.0	2.9
Product liability		
Passenger car	2.8	2.7
Light truck	2.8	2.7

Other Responses (new areas of legislative/regulatory activity):

PC = Passenger Car LT = Light Truck

Vehicle handling
Short Term - PC: 2; LT: 2

ITS Regulations
Short Term - PC: 4; LT: 5
Long Term - PC: 5; LT: 5

Active safety, ABS
Short Term - PC: 3; LT: 3
Long Term - PC: 2; LT: 2

CO_2
Short Term - PC: 2; LT: 2
Long Term - PC: 1; LT: 1

ITS Standards
Short Term - PC: 4; LT: 4
Long Term - PC: 5; LT: 5

"Green" laws
Short Term - PC: 3; LT: 3
Long Term - PC: 2; LT: 2

SIR detection
Short Term - PC: 2
Long Term - PC: 1

Fire Protection
Short Term - PC: 2; LT: 2
Long Term - LT: 2

Selected edited comments

- In the long term I see more "global standards" (i.e., offset frontal) and harmonization.
- The new Federal Test Procedure (FTP) plus all of the off cycle requirements are the same as a standards change. EPA should allow self-certification with stepped up surveillance.

Discussion

In the short term (1998-2002), for both passenger cars and light trucks, panelists forecast more restrictive regulation and legislation in the areas of vehicle emission standards, occupant restraint/interior safety and vehicle integrity/crashworthiness. Little or no change is forecast for alternate fuel/power source, antitheft equipment, regionalization of national standards and product liability.

In the long term (2003-2007), for both passenger cars and light trucks, panelists forecast more restrictive regulation and legislation in the areas of vehicle emission standards, occupant restraint/interior safety, vehicle integrity/crashworthiness and alternate fuel/power source. Little or no change is forecast for antitheft equipment, regionalization of national standards and product liability.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of those shown in the following table.

U.S. Federal Regulation and Legislation		
	Short Term 1998-2002	
Legislation/Regulatory Activity	Mfr.	Supp.
Vehicle integrity/crashworthiness		
Light truck	2.0	2.4
Regionalization of national standards		
Passenger car	2.7	3.1
Light truck	2.8	3.1

For the areas where there is a statistically significant difference, manufacturers forecast somewhat more restrictive legislation/regulation than suppliers.

Comparison of forecast: MKT-6

Responses from Technology and Marketing panels were statistically significantly different for the activities shown in the following table.

Scale: 1 = Much more restrictive 3 = No change 5 = Much less restrictive

Legislation/Regulatory Activity	Mean Response			
	Short Term 1998 - 2002		Long Term 2003 - 2007	
	Technology	Marketing	Technology	Marketing
Vehicle emission standards				
Passenger car	2.6	2.2	--	--
Light truck	2.4	2.1	2.0	1.8
Anti-theft equipment				
Passenger car	3.0	2.8	2.9	2.6
Light truck	3.1	2.8	3.0	2.6
Regionalization of national standards				
Passenger car	--	--	2.9	2.6
Light truck	--	--	2.9	2.6
Product liability				
Light truck	--	--	2.7	2.5

Trend from previous surveys

Results for the current and past two surveys are quite similar, with a tendency in the direction of no change from past to current surveys.

Strategic consideration

The modest trend in the current forecast for only slightly more stringent regulations and legislation should be good news for both manufacturers and consumers. Previous Delphi surveys forecast more stringent regulation and legislation. Vehicle affordability is currently a problem for vehicle buyers, and any additional regulations and legislation in the areas addressed in this question are likely to add cost to the vehicle.

Panelists do forecast more restrictive legislation, however, in the areas of alternate fuel/power source, occupant restraint/interior safety, vehicle integrity/crashworthiness and vehicle emissions. Legislation in these areas could have a dramatic impact on the cost and utility of a vehicle.

Tech-13 addresses the forecast penetration of alternate fuel/power sources. The obstacles to their introduction are discussed under strategic considerations in that question. Legislators should consider these obstacles before implementing legislation.

The amount of additional regulation and legislation that is enacted will be to a large measure influenced by upcoming political elections, as has been noted in comments to questions throughout this forecast. We would hope that future legislation will be developed with the cooperation of the industry and with a higher level of understanding of the technical and economic issues that abound in this arena.

TECH-17. What new regional regulations/legislation do you anticipate in the next decade that will impact the design of vehicles? Please comment on design changes required and the region affected.

Other Responses:

Regulation/legislation	Geographical Region affected	Design Requirement
Air pollution: *(29 responses)*		
Air pollution credit focused on vehicles	California	Higher-priced emission control
Alternate fuels/electric (2 responses)	East and West Coasts	
Ambient pollution levels (2 responses)	Various urban areas	Vehicle testing, CARB regulations
Annual emission testing	U.S. urban areas	Aftermarket emissions equipment
Clean air	All U.S.	Hybrid vehicle
Controls on pollutants and stricter emission regulations for both manufacturers and suppliers	Continue with urban areas and later rural	Relocation of production to uncontrolled or foreign, the use of cleaner technologies.
Electric vehicle mandates	Northeast	Accommodation of cold climates
Emissions (2 responses)	California	Alternate power plant
Emissions (6 responses)	N.E. ,East Coast, Great Lakes	California standards
Engine emissions	Major cities and population areas	Fuels
Expanded ULEV	California and Northeast	Better batteries
Flex-fuel capability	Midwest	Alcohol-resistant componentry
High-density traffic limits	Major urban areas	Restricted access to area
New FTP	All	Quick light off catalyst
New off-cycle advisories	All	Lean weight engines
Particulate standards	Federal	Catalyst trap
Standardization of vehicle emission testing requirements (instead of state to state)	Whole country	Onboard diagnostics, maintenance, repair and tampering monitoring
Tighter NOx and HC	California	Engine/catalyst
UL or zero emission	Major cities	Electric or hybrid
Ultra-low emissions	California	Zero-emission vehicles
Vehicle access to high emissions area	Los Angeles, Denver	Smaller and/or less access
Fuel economy: *(3 responses)*		
40 mpg	U.S.	Downsizing/alternate fuels; diesel, natural gas
Fuel economy	Asia/China	Higher
Upgrade CAFE standards	North American	Vehicle downsizing
Global warming: *(2 responses)*		

CO_2 – taxes	Europe/Japan	80 mpg - cars
Greenhouse gases	All	Lightweight vehicles
Recycling: *(15 responses)*		
Increased regulation for recycling	All	Common materials
Recyclability	California	Fluids
Recyclability (12 responses)	Nationwide	Identification, ability to separate, percent recyclable, standardize plastics, total life cycle or percent recycled material to be specified
Tire recycling	Midwest	Reusable as fuel
Safety: *(2 responses)*		
Passive restraint	All	Side, roof impact
Seat belt laws	Midwest	More visibility, comfort
Misc:		
ITS standards	Worldwide	Interoperability
Limited truck traffic	Cities	More small trucks
Public transportation	Major metropolitan areas	
Vehicle height	Europe	Reduce

Selected edited comments

- 1) Noise legislation will continue to become more restrictive for commercial vehicles on a worldwide basis; 2) restricted use of conventional personal vehicles in urban centers will increase usage of rental electric cars.
- I expect new mpg requirements if Al Gore is elected president.
- Manufacturing plants will be able to take old vehicles apart and reuse the parts.
- New high-load/high-speed and with air-conditioning emission tests are currently being implemented. OBD II is going nationwide. Emission regulations are all approaching the ULEV or ZEV levels. Therefore, I don't see very much in new emissions regulations at regional levels.
- The ability to separate materials, fluids, etc., will be required.
- There will be smaller cars—one or two occupant requirements and perhaps a wheelbase of overall length limitations in high traffic density areas.
- We can't have any more regional regulations than we now have - EPA/CARB.

Discussion

Air pollution received the most responses (29) from panelists related to new regional regulations impacting the design of vehicles. The issue of recycling received the second highest response (15).

Manufacturer/supplier comparison

. Manufacturer/supplier comparisons are not done for open-ended questions.

Trend from previous Delphi surveys

This question was first asked in the 1996 Delphi VIII. Emissions regulations were the most frequently mentioned, followed by recycling. This is consistent with the current forecast.

Strategic considerations

Panelists forecast that additional regional regulations/legislation related to air pollution will be implemented in the next decade. California has had more strict vehicle emission requirements than the rest of the United States for two decades. Other states may adopt California emission standards, but may not develop standards of their own. Panelists expect other regions, particularly the Northeast, to endorse California requirements. The interest in mandating the sale of electric vehicles is of particular concern to manufacturers. As noted in Tech-13, this technology is currently, and may remain for some time, a hard sell to consumers—particularly in cooler regions of the country.

Regional regulations related to recycling are also forecast, although most comments (regarding recycling) were related to national regulations. There is already considerable legislation in Europe. Panelists' comments imply that they expect similar legislation to come to this country. To the credit of the automotive industry, most of the vehicle is currently recycled. Legislation would likely relate to those materials not currently widely recycled.

TECH-18. What is the anticipated global trend toward sharing of vehicle platforms and technologies in the coming decade?

Scale:	1 = significantly more sharing 3 = unchanged 5 = significantly less sharing

Within Same Company	Mean Response
Sharing of component sets	1.4
Sharing of vehicle platforms	1.6

Between Companies	Mean Response
Sharing of component sets	2.3
Sharing of vehicle platforms	2.8
Sharing of manufacturing facilities	2.7

Selected edited comments

- All manufacturers will continue to pursue increased reusability, fewer unique platforms/components, etc., to provide overall cost/investment.
- The cost to develop new technologies is increasing. The supply base is consolidating. Technologies will be shared.
- The OEM-supplier relationship may get closer, but not intercompany sharing of facilities.

Discussion

Panelists forecast significantly more sharing of component sets and vehicle platforms within the same company in the next decade. They forecast somewhat more sharing of component sets between companies, but little change in the sharing of vehicle platforms and manufacturing facilities between companies.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers, with the exception of those shown in the following table.

Global Sharing Within the Same Company		
	Mfr.	Supp.
Sharing of component sets	1.3	1.6

Manufacturers forecast slightly more sharing of component sets within the same company than do suppliers.

Trend from previous Delphi surveys

This question was not asked in this format in any previous survey.

Strategic considerations

Sharing of component sets and vehicle platforms is an element of reducing total vehicle cost. With the drive to downsize organizations, sharing of components and vehicle platforms will allow the design and manufacture of components and vehicles with a smaller workforce and lower capital requirements. Sharing is particularly important for components that are transparent to the customer. Considerable cost savings can be realized with no loss in customer satisfaction. Savings result in the areas of design, manufacturing, purchasing, service and inventory. Of course, actually managing this within a large company as we begin to do "common" is a formidable undertaking (as we are all discovering). Still, the incentives are very strong.

Panelists forecast an increase in sharing within a company but not between companies. This is likely because of a desire to obtain or retain a competitive advantage within the industry. At the component level, there is a considerable effort between the Big Three through the U.S. Council on Automotive Research (USCAR) and its Strategic Standardization Board. Progress is being made, and component standardization could accelerate in the years ahead.

TECH-19. All manufacturers are working on approaches to reduce overall vehicle costs. Please rate the expected cost savings by 2007 from each of the following factors.

Scale: 1= major cost savings, 3 = moderate cost savings, and 5 = no cost savings

Cost Savings Rating by 2007 Source of Cost Savings	Mean Rating
Deproliferation of platforms/models/parts	2.0
Internal standardization	2.1
Manufacturing process improvements, productivity gains	2.2
Reduced design/development cost	2.3
Cross-company standardization	2.5
New supply patterns e.g., off-shore or outside versus inside	2.6
Reduced supplier prices to OEM	2.8
Lower distribution/sales costs	2.8
Decontenting	3.1

Other Responses:

Globalize business systems - 1

External standardization/globalization - 2

More modules/subassemblies - 2

Selected edited comments

- Increased emissions and safety standards plus increased labor costs will more than offset the above savings. Vehicle costs will continue to rise at a rate that exceeds inflation.
- Standardization will reduce costs the most. Consider deproliferation as a form of standardization. This leads to reduced design/development cost.
- The key to cost efficiency is the delegation of responsibility for cost control to the people doing the work. That means planning, education, "process" control and having the "body" (the company) act as one whole. Workers (engineers, manufacturing and managers, too) must be problem identifiers and solvers. That will allow the above list to be achieved. Control at all levels. And, involved people are the key.
- There should be a consolidation and/or elimination of some marketing divisions, e.g., make all GM vehicles available through all dealerships.
- Trends should be toward global platforms, global sourcing, and shorter development periods.
- We need "reduced supplier prices to the OEM" through total cost management/supply.

Discussion

The factors forecast to provide the greatest vehicle cost savings by 2007 are deproliferation of platforms/models/parts, internal standardization, manufacturing-process improvements and productivity gains, and reduced design/development cost.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of those shown in the following table.

Cost Savings Rating by 2007		
	Mfr.	Supp.
Lower distribution/sales costs	2.5	3.1

Manufacturers forecast slightly higher cost savings from lower distribution/sales costs than suppliers.

Trend from previous Delphi surveys

This question was not asked in this format in any previous survey.

Strategic considerations

Panelists forecast that the greatest vehicle cost savings will come from deproliferation of platforms/models/parts. Major costs savings result from reducing the number of vehicle platforms and taking a number of models off of a given platform. Exterior appearance may be very different between models, but the major vehicle systems such as chassis, suspension and engine may be common. For systems that are transparent to the customer, there is no value added by having different systems between models. Likewise, reducing the number of models reduces design and development cost, tooling cost, and parts inventory. Similar cost savings result with common components or parts. A simple component such as a turn-signal lever is frequently proliferated between models for style, color, cruise-control type, presence or absence, and windshield wiper control. There have been cases in the past where this component had more than 40 separate part numbers on four models off of one platform, where perhaps five could have sufficed. Where is the value for the customer? Similar examples are commonplace for other parts. A marketing division may argue that they have special requirements, but the total cost should be evaluated in providing this differentiation.

Manufacturing process improvements are evolving in the use of lasers, hydroforming, and many other techniques. Panelists forecast that this area will provide substantial cost savings in the next decade. Specific comments by panelists on this subject are included in Tech-20.

Finally, reduced design and development costs will come from a number of sources. Increased use of computer modeling will reduce the number of prototypes required and the amount of testing required. Rapid prototyping will provide test material in a quick and cost-effective manner. Increased use of statistically designed experiments will reduce the amount of testing and prototypes required.

Vehicle affordability is a concern today. As vehicle content is added to meet future safety and emissions control requirements, the pressure to reduce total vehicle cost will intensify. The comment related to delegating responsibility for cost control to the people doing the work is particularly noteworthy.

TECH-20. What new manufacturing processes will be introduced in the next decade that will reduce vehicle cost?

Responses:

Adhesive for fasteners, snap together for fasteners, more molding of plastics, plastics for steels

Advanced composites with low production cost and design complexity to lower cost by combining parts in a common part

Advanced metal forming, powdered metal technologies

Affordable method to utilize lightweight materials such as carbonfiber (2 responses)

Composite components, new heating/cooling systems, energy recapture

Continued closure between computer-aided design and computer-aided manufacturing

Continued use of lean manufacturing.

Electroforming process of thin wall material, eliminating the need for progressive dies

Electronic quality checking, weld integrity, paint thickness, fit tolerances

Enlightened labor agreements

Fabricated engines—no castings

Flexible machining and stamping centers that can make changeovers at very minimal retooling cost and with little or no "downtime"

Flexible manufacturing systems for stamped components; shorter lead-time production tooling using rapid prototyping-type technologies.

Flexible manufacturing tooling systems and common processes and procedures

Flexible manufacturing tooling systems and common processes and procedures.

Flexible, automated manufacturing systems (North America)

Fractal manufacturing

Generic body manufacturing process; generic chassis modular assemblies

Global standards—safety and emissions

High-speed flexible machining modules.

Hydroformed body structures (5 responses)

Increased robotic fabrication of assembly

Input will have to come from the suppliers, the Big Three manufacturing development is nil. All new development will only come from suppliers trying to make their products more competitive.

Integrated design and manufacturing process modeling—simulation; improved education of manufacturing and assembly workers to design intent.; more control of breaks in routine; more rapid tool and process changeover; better modeling of process flow

Interactive workstations will provide training or "refresher" training to workers, reducing training costs and repair costs.

Laserwelding, laser cutting, bonding

Lean initiatives

Lean manufacturing techniques will become institutionalized.

Less expensive tooling; longer production runs of basic hardware components; significant simplification of "hidden," nonfeature parts

Lightweight material-manufacturing processes

Metal-matrix composite materials, metal injection molding

Molded "body color" panels; optimized energy absorber parts

More automated processes eliminating bottlenecks and human errors

More automation of assembly and joining

More flexible assembly plants

More flexible body shops

More modular assembly (10 responses)

Plastic and composite molding and forming, aluminum forming

Reduced tier 1 supply base—rationalization

Robotics, metal extrusions

Space frames from low-cost roll-forming technology combined with plastic/composite body panels

Spray steel coating of cylinder bores (aluminum or magnesium) so that cast-in-place or pressed-in liners are no longer required.

Standardized component manufacture/assembly processes—sharing between different product lines; improved quality control, piece cost improvement through improved high stability—conformity of component/tooling design, etc.

Structural bonding

Ultrahigh-speed machining, pull-through system from raw material to customer, net-shape forming.

Discussion

Numerous manufacturing processes are suggested by the panelists that are either beginning to be used or will be introduced in the next decade to reduce vehicle cost. The most frequently mentioned are the use of modular assembly and hydroforming of body structures.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

The need to reduce vehicle cost as a result of the vehicle affordability issue and intense competition between manufacturers will make it imperative in the next decade to pursue all potential cost-saving initiatives. Many such manufacturing initiatives have been noted by panelists. There are a large number, which is not surprising considering the size and complexity of the industry as well as the intense level of current development underway. Furthermore, extensive global benchmarking is ensuring that the best processes, wherever they are being used in the world, will be considered for application here in North America. The manufacturers and suppliers that are the most successful in the execution of these initiatives will likely be at a competitive advantage by the end of the next decade.

TECH-21. Decontenting has two major elements: removal of equipment and relaxation of design specifications. What percent of the decontenting cost reduction by 2007 will be achieved by each element?

Decontenting Cost Reduction By 2007	Median Response	Interquartile Range
Decontenting Element		
Removal of equipment	50%	25/80%
Relaxation of specifications	40	10/70

Selected edited comments

- Consumers will not allow relaxation of requirements. If anything, the expectations are getting more demanding. If cost savings are to be achieved with only these two elements, 100 percent will have to come from removal of equipment, although I question the ability to do much decontenting and still meet consumer expectations.
- Customer will not accept the removal of equipment.
- Decontenting by removal of equipment is missing the point. The customer does not want less for less, they want more for less.
- Decontenting is the antithesis of customer satisfaction. The low-cost manufacturer controls his own destiny.
- Eliminate overdesign.
- Emissions will have the most relaxation.
- For the Big Three, relaxation of standards is not an option due to marginal quality and durability, but "foreign" manufacturers will consider this.
- I do not see much decontenting happening.
- I really do not think there can be much decontenting. There is too much global competition.
- Only items not wanted by the customer can be "decontented" so the impact of this activity will be minimal if not immeasurable.
- Removal of equipment will be based on customer value.
- Some specifications require major investment and piece cost for achievement. These specifications are usually customer-specific and not realistic when viewed in the light of other customers' specifications, or "real world" use.
- Specifications cannot be relaxed significantly without unacceptable losses in quality and safety.
- Specifications will be "rationalized" with respect to true/customer value.
- Specifications will be relaxed by knowing better how to set them in the first place. Customer function will not be sacrificed in this process. Too many current specs are too conservative.
- The competitive environment will not support decontenting. It is a one-way street when you add content.

Discussion

Panelists forecast that decontenting of the vehicle will come almost equally from removal of equipment and relaxation of specifications.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was not asked in this format in any previous survey.

Strategic considerations

In Tech-19, panelists forecast that a moderate cost savings would be obtained from decontenting by 2007. This question examines more closely the elements of decontenting. A number of panelists noted in their comments that the customer will not tolerate decontenting either by removal of equipment or relaxation of specifications asserting that the customer wants "more for less, not less for less." A comment that may be significant is: "Specifications will be relaxed by knowing better how to set them in the first place. Customer function will not be sacrificed in this process. Too many current specs are too conservative". It may be possible to reduce specifications in a manner that is transparent to the customer. It may be that tolerances or material specifications are set tighter than is required to provide adequate function. The challenge will be to sort out the overly stringent from the required specification.

It should be noted that the interquartile range of responses is very wide. This is an indication of uncertainty or disagreement between panelists. The comments certainly reflect different opinions on this subject.

TECH-22. How important are these elements of competition to the traditional domestic manufacturers currently and in the year 2007?

Scale: 1 = very important
3 = somewhat important 5 = not important

	Mean Response	
Key Elements	**Currently**	**In the year 2007**
Cost to the manufacturer	1.4	1.4
Quality/reliability/durability (QRD)	1.6	1.5
Vehicle sales price	1.9	1.6
Reduced lead time	2.1	1.8
Safety	2.2	1.8
Sales and service	2.4	1.8
Corporate product reputation	2.1	1.9
Styling/fashion	2.0	2.0
Fit and finish	2.2	2.1
Fuel economy	3.0	2.1
Vehicle ergonomics	2.7	2.2
Environmental responsibility	3.3	2.3
New technology/product innovation	2.9	2.4
Ride and handling	2.5	2.4
Performance	2.5	2.5
Image of good corporate citizenship	3.0	2.7

Selected edited comments

- Automakers are businesses. Business is still run for profit. Banks and investors move money based on profit. Cost issues are per force, number one. Good management requires meeting that objective first as it is related to survival. Product and service issues are important too. A good manager must balance his objectives. A strong executive will make these product issues corporate objectives. The industry is moving in that direction, but it is a big business with much inertia.
- Reduced lead time and delivery to the customer are particularly important.
- The domestic manufacturers will have less market share and will be required to be competitive.

Discussion

Panelists forecast that the most important elements of competition to the traditional domestic manufacturers, currently and in 2007, will be cost to the manufacturer and quality/reliability/durability.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of those shown in the following table.

Elements of Competition				
	Current		2007	
Key Elements	Mfr.	Supp.	Mfr.	Supp.
Quality/reliability/durability (QRD)	1.4	1.8	1.3	1.7
Corporate product reputation	1.8	2.3	1.6	2.2
Reduced lead time	1.9	2.4	-	-
Fit and finish	2.0	2.4	-	-
Sales and service	2.0	2.6	-	-

Manufacturers rated more important than suppliers all elements of competition for which there was a statistically significant difference in responses.

Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey for current importance. Future importance was not rated.

Results of the current and past two surveys are similar for all elements except those noted below. In all cases noted below the trend is toward less importance placed on the key element.

Current Importance of Elements of Competition			
Key Elements	Mean Forecast		
	1994 Delphi VII	1996 Delphi VIII	1998 Delphi IX
Environmental responsibility	2.2	2.8	3.3
Fuel economy	2.2	2.6	3.0
New technology/product innovation	2.1	2.4	2.9
Sales and service	1.8	2.0	2.4

Strategic considerations

In spite of the decline in importance placed on the factors shown above, it should be noted that all elements are considered to be at least somewhat important currently. It is well stated in one of the comments that businesses are run for profit, and therefore elements directly impacting profit must be considered the most important. Cost and quality are obviously closely tied to profit. It may not be as apparent how a factor such as environmental responsibility impacts profits. In the short term, addressing environmental problems are a cost to the corporation and negatively affect profits. In the long term, however, the company that neglects environmental responsibility may find a negative response from customers that will affect profits. Witness the current situation of the tobacco companies: short-term profit versus long-term detriment.

The automotive executive faces a challenging task in providing the proper balance to all of the many factors affecting his/her business. This challenge increases as the competition becomes more global in nature and market share is fiercely coveted by many parts of the world.

It is also important to recognize that customers are not uniform in their response to these factors. Different customers will rank order the factors differently. Consequently, they are all important.

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TECH-23. What percentage of product design and engineering for North American-produced passenger cars is and will be performed in North America and offshore by the traditional-domestic vehicle manufacturers?

		Median Response		Interquartile Range		
Design/Engineering Site	**Currently**	**2002**	**2007**	**Currently**	**2002**	**2007**
North America	90%	80%	70%	90/90%	80/85%	65/75%
Offshore	10	20	30	10/10	15/20	25/35

Selected edited comments

- Competition dictates global engineering for a global market. North American engineering teams, along with engineers in other countries, will develop products for the global market.
- Currently, design centers exist around the world. The tight labor market in the U.S. for skilled designers/engineers will only escalate the cost to hire and retain good employees. Since the OEMs do not recognize cost increases, the cost of design must decrease. Many suppliers in other industries are building design centers in India to take advantage of highly skilled workers at 1/10 of the cost.
- Due to "information-age" communications technology becoming very common, the projects will be done by more and more "virtual" teams operating in many locations at once. This will make it harder to decide where the work is done.
- Engine design expertise is being handed over to consulting companies like Ricardo, FEVAVL. If this trend continues, U.S. manufacturers will be at the mercy of these people. They will find this to be more expensive in the long run as there will be no incentive by these companies to maintain costs.
- Engineering and design will become more global to fit the needs of the local markets (Asia/Europe/India), where the vehicles are built and sold. This will improve efficiency and reduce costs, as well as cater to the needs of the local area.
- Engineering/design will become more global to reduce costs and reduce development time.
- Examples: Ford-Mazda/KIA, GM-Toyota/Suzuki, etc.
- Global design is the next step for Big Three.
- Globalization will result in more offshore design where engineering is less costly and local content will mean more manufacturing plants offshore.
- I have seen the engineering facilities in other countries. I have also seen people I know transferred to these facilities. The trend towards globalization is definitely pushing these jobs around the world.
- Joint global development will emerge.
- Many components are designed offshore. That trend will deepen, but OEMs will share vehicle design responsibility with platforms being designed systemically on one side of the water.
- More "modularization" will result in more of the product design and engineering work being transferred to capable, global suppliers.
- The body in white by the Big Three and components by suppliers will move design offshore to be competitive.

- The consumer will dictate style and content, while costs will dictate where design and/or engineering is accomplished.
- The key words in this question are "passenger car." A lot of these will truly start to be engineered on a global basis.
- There is no question that the traditional-domestic manufacturers are becoming more global (in spite of the unions). Considering just component design, the North American numbers would be much lower. Of course, you're including Mexico and Canada in this total. Is there really a difference in producing a component in China or Mexico? Also, I would suggest differentiating engineering and manufacturing so that you can get a more accurate view of industry trends.
- There will be global engineering by Ford for Ford; and GM for GM, etc.
- There will be more and more global design spread throughout the world.
- This assumes growth in Asian markets drives toward customer-specific design, but basic powertrain and body design remains localized in North America.
- While the globalization of design/engineering will initially dilute the North Amerian locations, limits will be reached due to maintained localized efficiency (and costs) as well as the benefit localized design brings to the end customer. Having worked for Toyota, it is obvious which vehicles had North American design involvement.
- With the creation and addition of STEP into all databases, the need to complete design locally is eliminated. The real need will be short lead times for all products and services. This will lead to a very quick transition between countries doing work.

Discussion

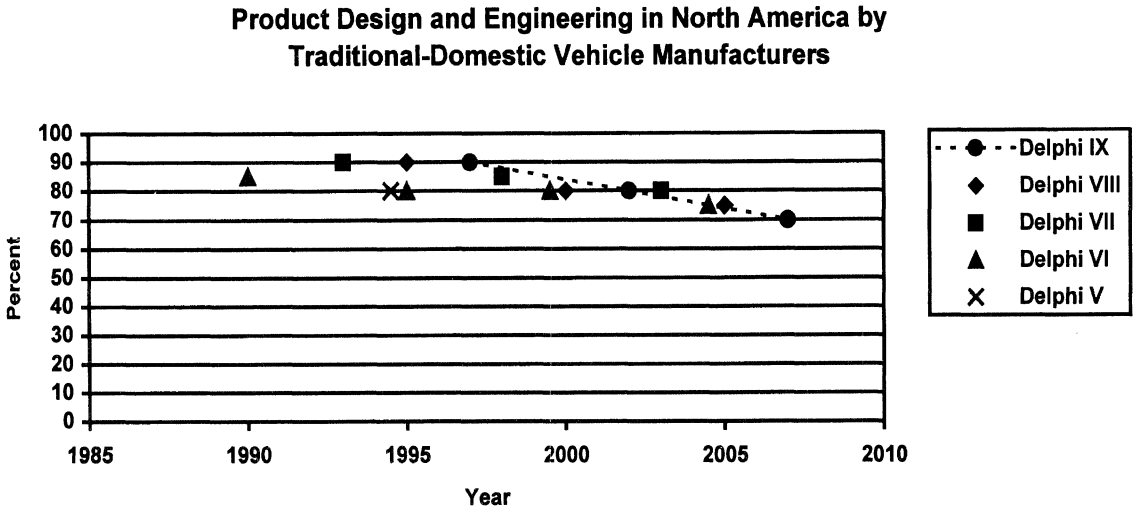
Panelists forecast that the traditional-domestic vehicle manufacturers will perform most of the product design and engineering for North American-produced passenger cars in North America through 2007. Offshore design and engineering is forecast to increase significantly, however, from 10 percent currently to 30 percent in 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

A comparison of results for this survey and the previous three surveys is summarized in the graph below.



The forecast trend for a decrease in product design and engineering in North America is similar to that of past surveys. The decrease forecast in past surveys may not have occurred, however. Previous forecasts would have the current value at about 80 percent, whereas the current estimate remains at 90 percent.

Strategic considerations

Two factors are currently prompting increased design and engineering offshore by the domestic manufacturers. The first is globalization. Increasingly, platforms are used worldwide. These platforms may be designed in North America, Europe, or some other parts of the world where design responsibility is assigned by the manufacturer. While this may result in vehicles sold in North America being designed offshore, other vehicles marketed in other parts of the world may be designed in North America. The net effect may be only modest changes in total design and engineering performed in North America.

The second factor is cost. North America is currently a relatively high-cost location for vehicle design and engineering. Other locations may be selected by domestic manufacturers and suppliers to control cost.

Offshore design and engineering of products marketed in North America create challenges in the areas of communication and sourcing. If a vehicle is designed offshore, computer systems must be compatible between designers and suppliers. If only part of the vehicle is designed offshore, the problem is even more complex in that the portion designed offshore must function and fit with the portion designed in North America. The coordination challenge is substantial, requiring both cultural change and the effective use of advanced computer and information technology. Leading companies in the future will function as if there are no boundaries separating countries around the world.

TECH-24. What percentage of product design and engineering for North American-produced passenger cars is and will be performed in North America and offshore by foreign owned vehicle manufacturers?

Design/Engineering Site	Median Response			Interquartile Range		
	Currently	2002	2007	Currently	2002	2007
North America	10%	20%	30%	10/20%	10/30%	20/50%
Offshore	90	80	70	80/90	70/90	50/80

Selected edited comments

- Engineering is still less costly offshore.
- For GM, off-shore design is done by Isuzu, Suzuki, Toyota, Saab, and Opel/Vaux-Hall.
- Foreign manufacturers are less likely to cede design control to North American offices.
- Manufacturing in North America will grow more quickly than design/engineering due to the engineering expertise required.
- Most of the engineering referenced above is done by U.S. suppliers.
- There is wide variation in how the different manufacturers approach the North American market. Toyota seems to be doing a lot of the engineering for the products in this country now that they have developed a core group of people in this country whom they can trust. Other firms seem to be doing all of the engineering in their home countries.

Discussion

The percentage of product design and engineering in North America for North American-produced passenger cars by foreign-owned vehicle manufacturers is forecast to increase from 10 percent currently to 30 percent by 2007.

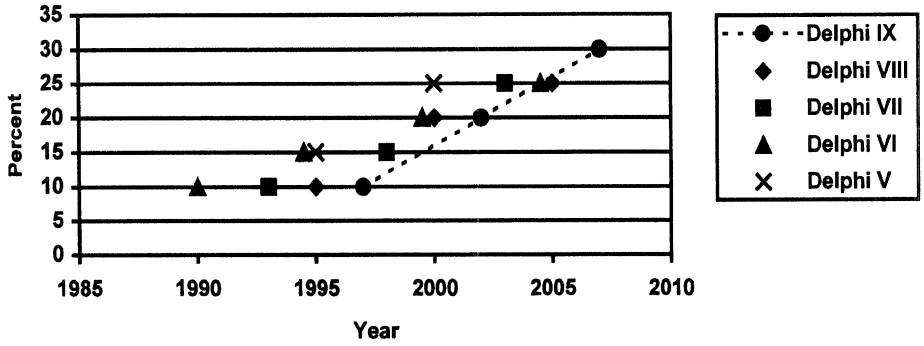
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

The results of this survey are compared to the previous four Delphi surveys in the following graph.

Foreign Owned Vehicle Manufacturers North American Product Design & Engineering Activity Forecast



There is generally good agreement between panelists in the last five surveys regarding the direction and magnitude of the product design and engineering in North America for North American-produced passenger cars by foreign-owned vehicle manufacturers. The change forecast in earlier surveys has not occurred, however. Previous surveys forecast 14 to 20 percent of design in North America in 1997, whereas the actual amount remains steady at 10 percent.

Strategic considerations

Panelists forecast that most design and engineering for North American-produced passenger cars for foreign-owned vehicle manufacturers will continue to be performed offshore in the next decade. The amount of this work done in North America is forecast to increase, however. As noted in one of the comments, Toyota is increasing design and engineering activity in North America. Other manufacturers like Honda may follow this lead, but movement has been slow to date.

As more vehicles are assembled in North America by foreign-owned vehicle manufacturers, engineering may move to North America in order to be near the growing supply base. There is also advantage in having engineering close to manufacturing facilities. The high cost of engineering in North America may deter foreign manufacturers from making this move.

The forecast moves of design and engineering to North America by foreign-owned vehicle manufacturers might at least partially offset the forecast moves of design and engineering offshore by the domestic manufacturers.

TECH-25. What percentage of parts, components and subassemblies do the traditional-domestic vehicle manufacturers source from these regions currently, and what percentage will they source in 2002 and 2007, assuming no domestic content legislation? Please use a dollar value basis in estimating percentages.

	Median Response			Interquartile Range		
Sourcing for Traditional Domestic Manufacturing Operations	**Current**	**2002**	**2007**	**Current**	**2002**	**2007**
Asia Pacific (except Japan)	5%	6%	10%	2/10%	4/15%	5/18%
Eastern Europe	1	2	5	0/2	1/5	2/8
Japan	10	10	8	5/15	5/14	4/14
North America (United States, Canada, Mexico)	75	70	65	65/83	60/78	50/75
South America	2	4	5	0/5	2/5	2/10
Western Europe	5	5	5	4/10	5/10	5/9

Selected edited comments

- China and Korea will begin to produce and compete with traditional areas.
- Components will be supplied by outside companies, but they will manufacture in the United States.
- I believe the sourcing will move to local countries and low labor areas of the world. The U.S. will remain as the design and build capital for vehicles.
- My estimates assume that the sourcing is for North American-produced vehicles. I do not foresee any major shifts due to the costs of transportation from "remote" locations.
- My opinion is that sourcing will continue to migrate to lower cost labor markets for labor-intensive items. Beyond the cost issue is the fact that too many U.S. citizens won't settle for assembly labor jobs. This type of job is ranked in their minds similar to farm labor.
- Since the sources (suppliers) are following the OEMs around the globe, the majority of sourcing will still be in the home-market areas.
- This is a result of the relocation and need for local production. The possibility to be shipping all around the world just does not exist due to long pipelines and logistic costs.

Discussion

Panelists forecast a decrease in North American sourcing of parts, components and subassemblies by the traditional-domestic vehicle manufacturers. North American sourcing is forecast to represent 65 percent of the total by 2007 compared to the current estimate of 75 percent. Sourcing from Asia Pacific (except Japan) is forecast to increase to 10 percent in 2007 compared to the current estimate of 5 percent.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of those shown in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

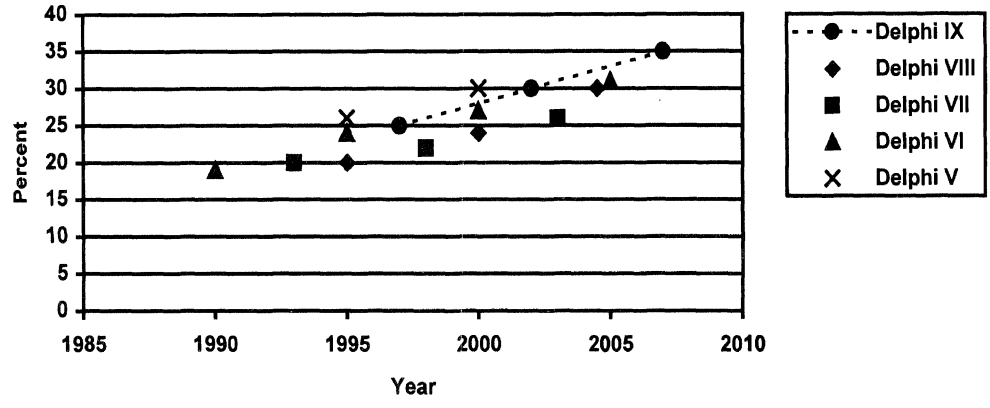
Sourcing for Traditional-Domestic Manufacturing Operations				
	Current Mean		2007 Mean	
	Mfr.	Supp.	Mfr.	Supp.
Eastern Europe	2.3%	4.2%	3.8%	6.7%

Manufacturers forecast somewhat lower sourcing from Eastern Europe than suppliers.

Trend from previous Delphi surveys

The percentage of parts, components and subassemblies forecast to be sourced outside of North America by the traditional-domestic vehicle manufacturers is summarized in the following graph for this survey and for the previous four Delphi surveys.

Traditional Vehicle Manufacturers Sourcing Outside of North America



This forecast is in general agreement with previous forecasts, although on the high side.

Strategic considerations

The forecast decrease in sourcing from North America by traditional-domestic vehicle manufacturers may be a result of several factors. These are generally covered in panelists' comments and include labor costs and suppliers following the location of vehicle assembly. A significant comment is that many components supplied to traditional vehicle manufacturers will be manufactured in North America by foreign suppliers.

Another significant comment relates to high logistics costs and "long pipelines" for components sourced offshore. These added costs and supply times might more than offset the lower labor costs of components manufactured offshore.

The potential loss of North American jobs as a result of the forecast decrease in sourcing from North America by traditional-domestic manufacturers may be partially or completely offset by the increase in sourcing to foreign manufacturers by domestic suppliers. Another offsetting factor may be the sourcing of parts from North America for vehicles designed in North America but assembled elsewhere. Finally, as domestic suppliers become more competitive on a global basis, the number of parts exported to other countries will increase.

It is interesting to note that sourcing from Japan is forecast to decrease in the next decade as sourcing to Asia Pacific, Eastern Europe and South America increases. Of course, trends in exchange rates could influence sourcing decisions significantly. Another factor that could influence

sourcing locations is the trend towards more standardized components within and between manufacturers. We will certainly see deproliferation of parts, components and systems on a global basis.

TECH-26. What percentage of parts, components and subassemblies do the North American production operations of foreign-owned vehicle manufacturers source from these regions currently, and what percentage will they source in 2002 and 2007, assuming no domestic content legislation? Please use a dollar value basis in estimating percentages.

	Median Response			Interquartile Range		
Sourcing for Foreign-Owned Manufacturing Operations	**Current**	**2002**	**2007**	**Current**	**2002**	**2007**
Asia Pacific (except Japan)	5%	8%	10%	5/5%	5/10%	8/14%
Eastern Europe	0	1	2	0/0	0/3	0/5
Japan	40	35	30	36/48	30/40	20/36
North America (United States, Canada, Mexico)	40	42	43	37/45	40/50	40/51
South America	0	2	3	0/3	1/5	2/5
Western Europe	8	8	6	5/10	5/10	5/10

Selected edited comments

- Asian manufacturers will continue to increase their North American content IF suppliers can meet quality targets and timing requirements. Europeans will continue to expand their North American production but will need European suppliers initially.
- Assuming reasonable exchange rates, Eastern Europe and Asia Pacific will grow as sources. Japan will come under more labor and exchange rate pressures, therefore, the supply will be less.
- Component production will become more widely dispersed, primarily at the expense of Japanese production.
- Eastern European manufacturers will become more prominent in the global scheme.
- I believe sourcing will move to local countries and low labor areas of the world. The United States will remain as the design and build capital for vehicles.
- It depends on the currency exchange, the development of South America and the development of Eastern Europe.
- It depends on the yen-to-dollar ratio.
- More European transplants will come to the United States. They will use North American suppliers more than the Asian transplants have. Asia Pacific will continue to increase its share because of pricing. Mainland China and India are included in Asia Pacific.
- North American content will depend on the supplier's ability to meet OE requirements for quality and timing. European transplants will need to "learn the lessons" of the Japanese and will rely on European supplier transplants or mergers.
- "Political pressures" to balance trade and currency exchange rates will influence the sourcing picture considerably.
- Statistics show that by the year 2005, only 5 percent of the people entering the U.S. workforce will be white males, and 47 percent will be of the Hispanic culture. I believe the United States is headed for a big change. Design and manufacturing locations will have to be more offshore than they are currently for companies to survive. The U.S. will become an assembly point for a

modular vehicle.

- The answer to this question highly depends on the country of origin of the foreign manufacturer.
- The big influence will be from domestic content legislation, so this question may be "no-meaning."
- There is a continuing trend to purchase from the NAFTA region.
- Western Europe continues to lose share due to worker productivity and labor costs.

Discussion

Panelists forecast that foreign-owned manufacturers will source fewer components and subassemblies from Japan by 2007 and slightly more from Asia Pacific, Eastern Europe, North America and South America. Panelists estimate that 40 percent of components and subassemblies are currently sourced in Japan, and forecast that this will fall to 30 percent by 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

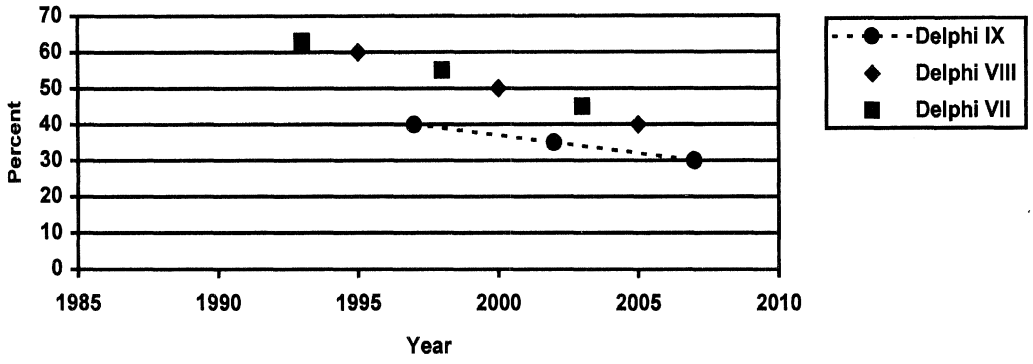
Trend from previous Delphi surveys

This question was first asked in the present format in the 1994 Delphi VII survey. Results of the current survey are compared to those of the two previous surveys in the following table.

	Current Estimate			Short-Term Forecast			Long-Term Forecast		
Forecast for year →	**1993**	**1995**	**1997**	**1998**	**2000**	**2002**	**2003**	**2005**	**2007**
Survey →	**1994 Delphi VII**	**1996 Delphi VIII**	**1998 Delphi IX**	**1994 Delphi VII**	**1996 Delphi VIII**	**1998 Delphi IX**	**1994 Delphi VII**	**1996 Delphi VIII**	**1998 Delphi IX**
Sourced from:									
Asia Pacific	5%	5%	5%	7%	9%	8%	9%	10%	10%
Eastern Europe	0	0	0	0	0	1	0	1	2
Japan	63	60	40	55	50	35	45	40	30
North America	25	30	40	30	39	42	35	40	43
South America	0	0	0	0	0	2	2	2	3
Western Europe	1	4	8	2	5	8	1	5	6

The current estimates have declined significantly for Japan and increased significantly for North America. Similarly, future forecasts are for continuation of this trend. The estimates and forecasts for Japan are summarized in the following graph.

Sourcing for Foreign-Owned Manufacturing Operations from Japan



The current estimate for sourcing from Japan is low compared to previous forecasts.

Strategic considerations

The forecast for increased sourcing from North America by foreign-owned vehicle manufacturers is good news for the North American labor market and, potentially, for North American suppliers. This good news must be tempered somewhat by the forecast for decreasing sourcing by traditional-domestic manufacturers (see TECH-25).

Although there certainly has been increased sourcing from North American suppliers by foreign-owned vehicle manufacturers, it must be noted that foreign suppliers have increasingly moved manufacturing operations to North America. These foreign suppliers account for some of the increased sourcing from North America. Additionally, foreign manufacturers are increasingly manufacturing high-cost components, such as engines and transmissions in North America. These components account for a significant percentage of the dollar value of sourced materials. The comments should be read carefully for the number of key points noted.

TECH-27. What percentage of components and subassemblies produced in North America do the traditional domestic manufacturers and foreign manufacturers source from each country currently and what percentage will they source in 2002 and 2007? Please use a dollar value basis in estimating percentages.

	Median Response			Interquartile Range		
Components Sourcing	**Current**	**2002**	**2007**	**Current**	**2002**	**2007**
Traditional Domestic						
North American (NA) content						
United States	70%	65%	60%	60/80%	50/75%	50/70%
Canada	15	15	15	10/20	10/21	10/20
Mexico	10	20	25	10/20	14/25	19/30
Foreign Manufacturers						
North American (NA) content						
United States	72%	65%	60%	60/80%	59/75%	50/70%
Canada	10	10	10	10/20	9/15	8/16
Mexico	14	20	25	10/20	12/30	15/36

Selected edited comments

- Cheap manufacturing costs and the lack of labor-union intervention in Mexico will continue to erode U.S. and Canada production. A more conciliatory relationship with U.S. labor could change this but based on historical events, it is unlikely.
- Directionally, I think it's safe to say that Mexico will become a more significant manufacturing source.
- Foreign manufacturers are more conscious of the move of sourcing to other parts of the region. They will maintain those common interests.
- Mexico will "be full"—Canada will continue to be third, as labor is still high.
- The law may have a negative impact on future sourcing in Canada.

Discussion

Panelists forecast that both traditional-domestic and foreign manufacturers will source a smaller percentage of components and subassemblies produced in North America from the United States and a larger percentage from Mexico in the next decade. Sourcing by traditional-domestic manufacturers from the United States is forecast to decrease from 70 percent currently to 60 percent in 2007. Similarly, sourcing by foreign manufacturers from the United States is forecast to decrease from 72 percent currently to 60 percent in 2007. Sourcing from Mexico is forecast to increase substantially by 2007 for both traditional-domestic and foreign manufacturers.

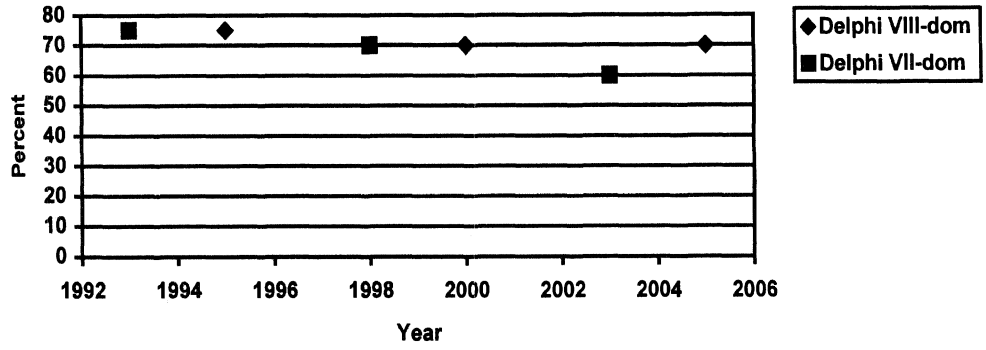
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

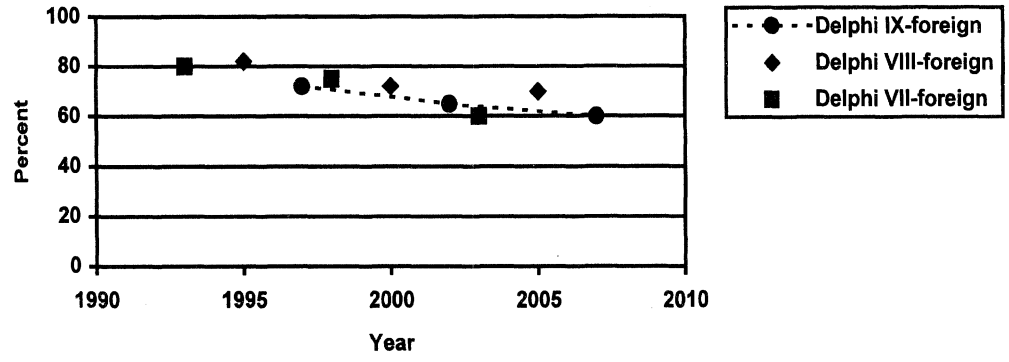
This question was first asked in the same form in the 1994 Delphi VII survey. A comparison of the results of the current survey and the previous two surveys for sourcing of components from the United States is shown in the following graphs.

Traditional Domestic North American Sourcing from the United States



Results of the current survey are consistent with those of the previous two surveys.

Foreign North American Sourcing from the United States



Results of the current survey are similar to those of the previous two surveys.

Strategic considerations

Low labor costs are certainly an incentive to manufacture parts in Mexico. Offsetting labor costs, however, are increased shipping costs, distance from design and engineering personnel and distance from assembly plants. Considering these tradeoffs, panelists forecast an increase in sourcing from Mexico in the next decade. This could have a significant negative influence on the labor market in the United States. The "giant sucking sound" may be coming through a small straw, but our panelists forecast that it can be heard.

Still, for parts, components, systems and modules that are produced with relatively low labor content (e.g., some engines can be assembled in as little as 2-3 hours of direct labor), there is little incentive to move outside of the United States for U.S. final assembly. For high labor content items, obviously, the reverse is true.

TECH-28. Currently, and in 2002 and 2007, what percentage of new tooling for North American-produced passenger cars and light trucks will be sourced in North America (Canada, Mexico, and United States)?

	Median Response			Interquartile Range		
New Tooling Sourced in North America	Current	Current	2002	2007	2002	2007
Passenger cars	80%	75%	70%	70/90%	70/85%	60/80%
Light trucks	85	80	70	75/90	70/85	65/85

Selected edited comments

- It's hard to tell. Tooling may be assembled in the United States with imported components.
- Low-cost Asian and Eastern European suppliers will gain ground but rapid prototyping will allow some reductions in tooling requirements. Japanese manufacturers will try to use more U.S. tooling sources.
- The North American tooling companies (including manufacturing machines) are now back in a competitive position with overseas machine tool builders and I don't see much shifting of sourcing in these time frames.

Discussion

Panelists forecast a decrease in the next decade in new tooling sourced in North America for both passenger cars and light trucks. North American sourced tooling in the year 2007 is forecast to be 70 percent for both passenger cars and light trucks compared to 80 and 85 percent currently.

Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers for all parts of this question. Responses for manufacturers and suppliers are shown in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

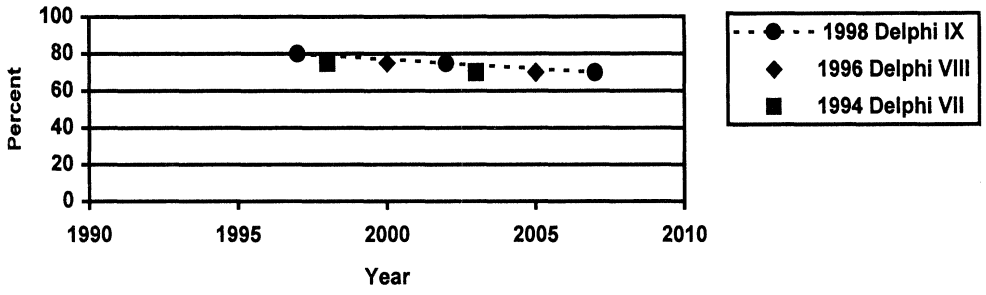
New Tooling Sourced in North America						
	Current Mean		2002 Mean		2007 Mean	
	Mfr.	Supp.	Mfr.	Supp.	Mfr.	Supp.
Passenger cars	74.8%	83.8%	69.2%	79.7%	63.8%	75.2%
Light trucks	72.2%	88.2%	67.0%	84.1%	61.9%	79.4%

Manufacturers forecast a lower percentage of current and future tooling sourced in North America than did suppliers.

Trend from previous Delphi surveys

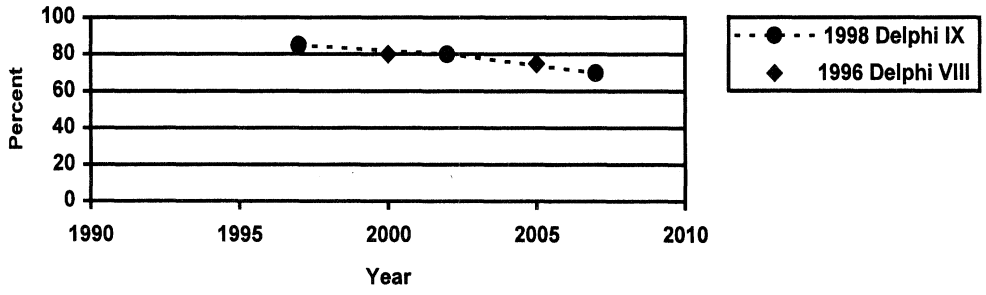
This question was first asked for passenger cars only in the 1994 Delphi VII survey. Light trucks were first addressed in the 1996 Delphi VIII survey. Results of the current and previous surveys are compared in the following graphs.

Passenger Car Tooling Sourced in North America



The current forecast for passenger cars does not follow previous forecasts. It indicates that a decrease in tooling sourced from North America is expected (as did the previous forecasts) but the decrease is further delayed in time.

Light Truck Tooling Sourced in North America



The current and previous forecasts for light trucks are in agreement.

Strategic considerations

Panelists' comments that North American tooling is back in a competitive position with overseas machine tool builders and that Japanese manufacturers will try to use more U.S. tooling sources are encouraging statements. In spite of these optimistic comments, the current forecast is for less tooling sourced in North America.

The machine tool industry is a key national resource and would be critical in time of an international crisis. Furthermore, the loss of jobs inherent in downsizing of the tooling industry may result in lower paying jobs for those displaced. This situation could affect vehicle sales.

Another significant consideration is the changing technology that could dictate new and creative approaches to tooling. For example, in recent years the number of stamping dies required to create an extensive sheet-metal component has been reduced significantly. Also, more automated and math-based tooling production could impact the sourcing trend.

TECH-29. Please give your expectations in months for current and future development cycles from concept approval through Job One for the reskinning of high- and low-volume passenger cars, maintaining current hardpoints.

	Median Response			Interquartile Range		
Future Development Cycles Maintaining Current Hardpoints	**Current**	**2002**	**2007**	**Current**	**2002**	**2007**
High-volume vehicle (production more than 50,000 units/year)						
United States	36	30	24	29/39	23/32	20/28
Japan	28	24	20	22/32	19/28	16/24
Europe	37	32	28	30/44	27/38	24/34
Low-volume vehicle (production less than 50,000 units/year)						
United States	32	27	24	25/38	22/32	18/28
Japan	24	22	18	18/30	17/27	15/24
Europe	36	30	27	30/40	25/36	20/32

Selected edited comments

- Short development time claims are often not considering total development time. Time will decrease with expanded use of simulation and simultaneous engineering but start-up quality problems could continue to haunt the Big Three. Less than 2 year cycles would blur the distinction in the consumer's mind and drive the accountants crazy.
- The numbers quoted by the various manufacturers do not use the same definition of "concept approval," nor do they all have the same level of validation at their definition of "job one," therefore it is very difficult to compare the numbers. It is my experience that the time from "clay" styling approval to the start of "high-volume" production is not as far apart as some of the current numbers would lead you to believe.
- There is no difference in our process for 100k or 30k.

Discussion

Panelists forecast that development cycle timing will be reduced by 24 to 33 percent for all manufacturers for high- and low-volume vehicles maintaining current hardpoints by 2007. Japanese manufacturers are forecast to retain the shortest lead-time as compared to manufacturers in Europe and the United States.

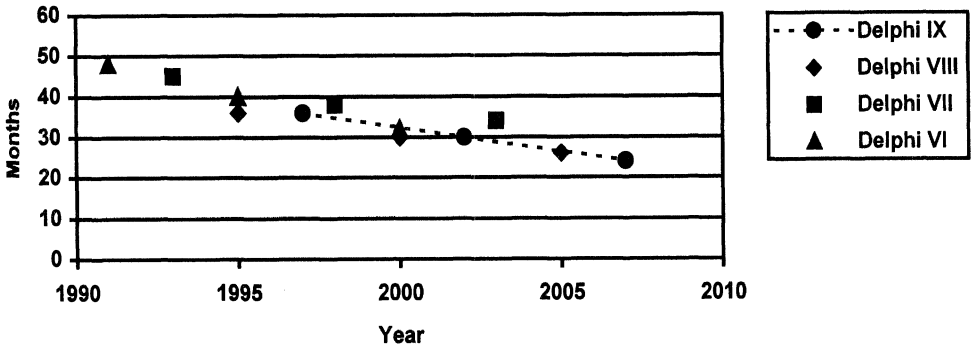
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

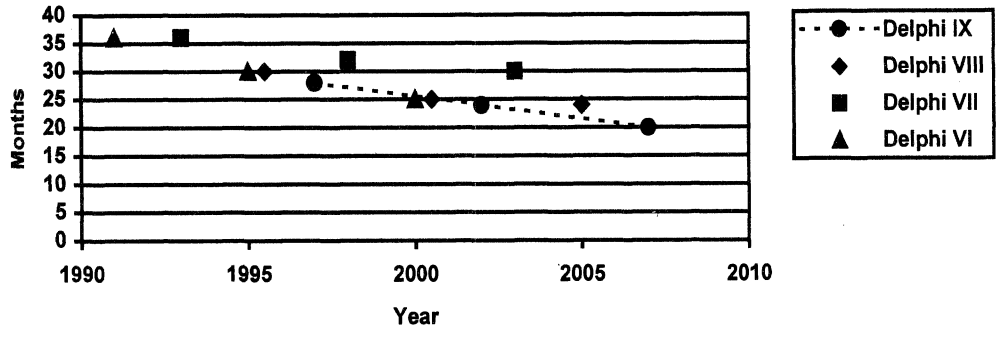
Trend from previous Delphi surveys

Results for the current and previous three surveys are compared in the following graphs.

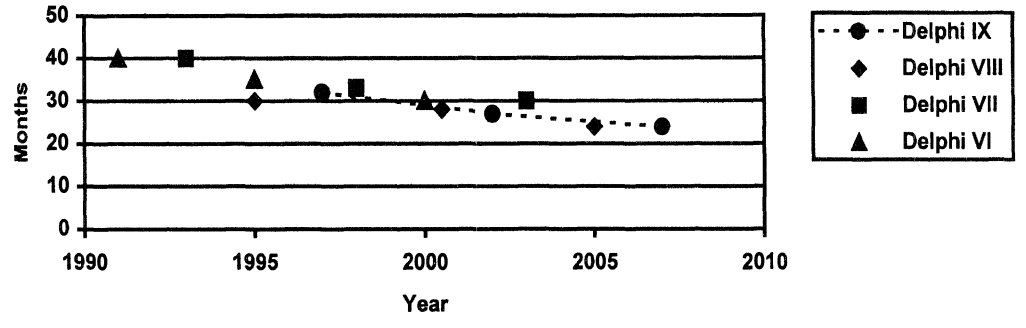
U.S. High-Volume Vehicle Development Cycles - Maintaining Current Hardpoints



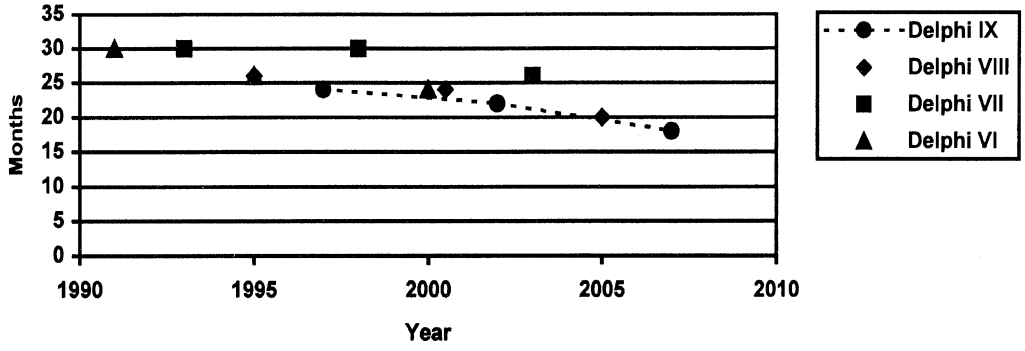
Japanese High-Volume Vehicle Development Cycles - Maintaining Current Hardpoints



U.S. Low-Volume Vehicle Development Cycle Maintaining Current Hardpoints



Japanese Low-Volume Vehicle Development Cycles
Maintaining Current Hardpoints



For high- and low-volume vehicles, results of the current survey are on the low side of the range of the previous three surveys. Results are very close to those of the previous Delphi VIII forecast. The fact that forecast results are lower in the last two surveys is likely an indication that development cycle time is decreasing at a rate greater than anticipated in earlier forecasts. In general, the results of all four surveys are in quite close agreement.

Strategic considerations

Short vehicle-development cycle time allows a manufacturer to bring a vehicle to market shortly after customer requirements are defined. The longer the cycle time, the less accurately the vehicle will meet the current expectations of the customer. In 1992, cycle time for U.S. manufacturers was about 48 months whereas cycle time for the Japanese manufacturers was about 36 months for a vehicle that maintained hardpoints constant. This 12-month advantage has been reduced to about eight months currently and is forecast to be only four months by 2007. In that same time frame, the cycle time for U.S. manufacturers is forecast to fall from 48 months to 24 months.

Clearly, the Japanese advantage has been reduced and is forecast to be reduced further in the future. This may allow U.S. manufacturers to bring out vehicles that are timely, and meet customer expectations to a much greater degree than in the past. European manufacturers are close to U.S manufacturers today, but are forecast to have less improvement through 2007.

When the clock starts, on-cycle timing is certainly an issue, as noted in the panelists' comments. Vehicle manufacturers have different requirements for starting the clock. In general, management approval of the clay model and business case, including financial, engineering and manufacturing analysis and approval of the product content determines the start of the process. Certainly there are differences in detail in this area, even within the same company. The greatest significance in the results of this question may be not that current cycle time is 36 months and is forecast to be 24 months by 2007, but rather the consensus that cycle time has been reduced by about 25 percent since 1992 and is forecast to be reduced another 30 percent by 2007. Further, the consensus is that the Japanese have an advantage in cycle timing and are forecast to retain that advantage, although to a lesser degree through 2007.

Another consideration is that, when pressed, a manufacturer may be able to reduce lead time considerably. Further, increasingly flexible and agile manufacturing systems should facilitate lead-time reductions. Also, highly disciplined processes, organizational structures that focus on the vehicle as a system and leadership that has both responsibility and authority, are critical to shortened lead-times. Finally, there is some evidence that reducing lead-time reduces design and development costs.

TECH-30. Please give your expectations, in months, of current and future development cycles from concept approval through Job One for new platforms that establish new hardpoints for high- and low-volume passenger cars.

	Median Response			Interquartile Range		
Future Development Cycles Establishing New Platforms	**Current**	**2002**	**2007**	**Current**	**2002**	**2007**
High-volume vehicle (production more than 50,000 units/year)						
United States	42	36	30	36/48	30/40	24/36
Japan	36	30	26	30/36	24/34	20/30
Europe	46	39	35	40/50	36/45	30/38
Low-volume vehicle (production less than 50,000 units/year)						
United States	38	33	29	35/47	28/37	24/32
Japan	33	30	25	26/36	23/32	19/30
Europe	42	36	31	36/48	30/42	37/36

Selected edited comments

- Low volume is the same as high volume on new platforms.
- Short development time claims are often not considering total development time. Time will decrease with expanded use of simulation and simultaneous engineering but start-up quality problems could continue to haunt the Big Three. Less than 2-year cycles would blur the distinction in the consumers mind and drive the accountants crazy.
- Time zero remains argumentative.

Discussion

Panelists forecast that development cycle timing will be reduced by 24 to 29 percent for all manufacturers for high- and low-volume vehicles for new platforms that establish new hardpoints by 2007. Japanese manufacturers are forecast to retain the shortest lead-time as compared to manufacturers in Europe and the United States.

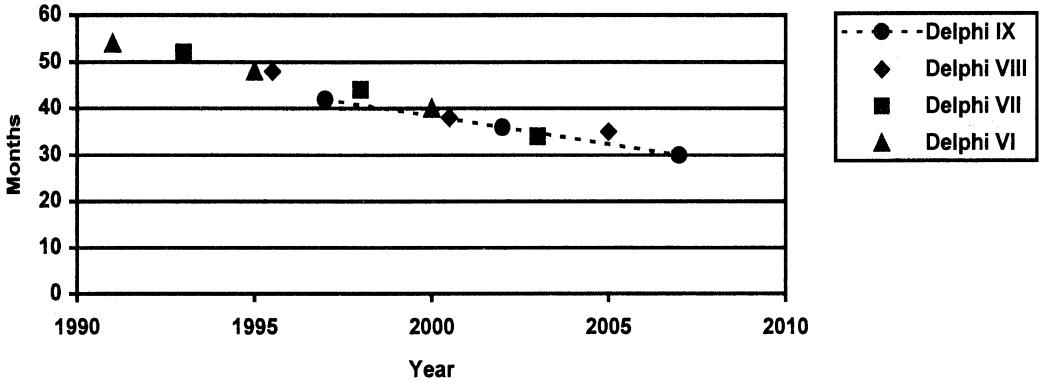
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

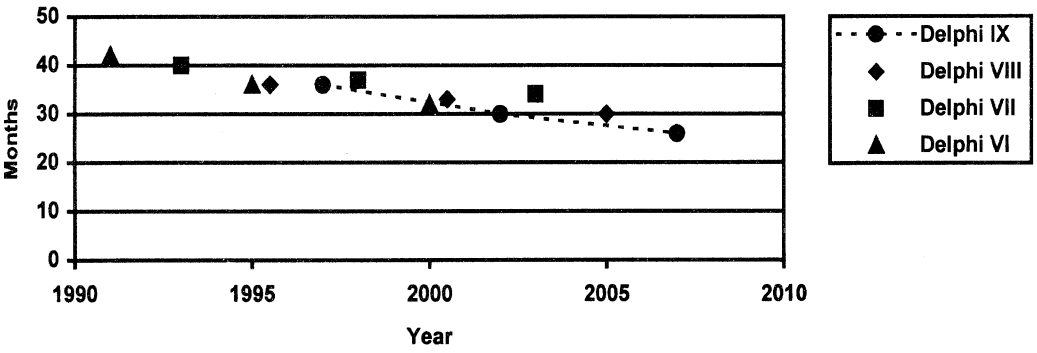
Trend from previous Delphi surveys

Results for the current and previous three surveys are compared in the following graphs.

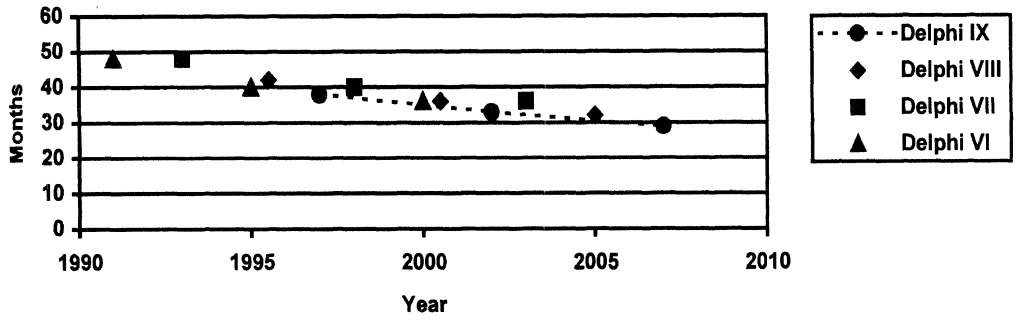
U.S. High-Volume Vehicle-Development Cycles - New Platform with New Hardpoints



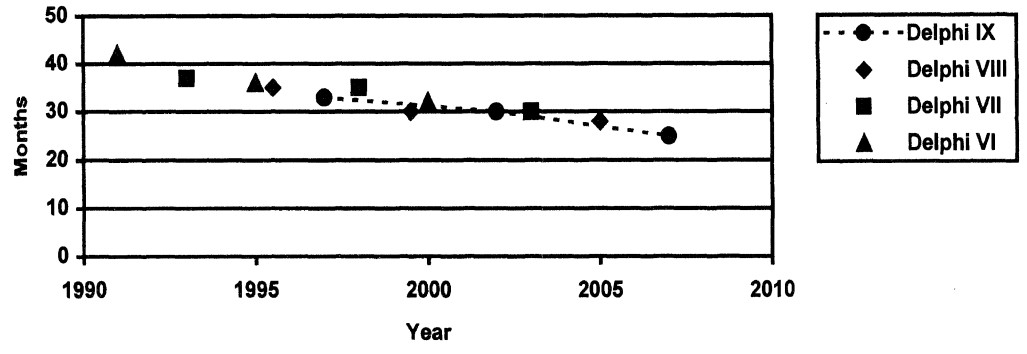
Japanese High-Volume Vehicle-Development Cycles - New Platform with New Hardpoints



U.S. Low-Volume Vehicle-Development Cycle - New Platform with New Hardpoints



Japanese Low-Volume Vehicle Development Cycles - New Platform with New Hardpoints



The results of all four surveys are in quite close agreement for all geographical areas and production volumes.

Strategic considerations

The strategic considerations that are noted in Tech-29 apply for this question as well.

The Japanese are forecast to retain an advantage in cycle time for new platforms compared to U.S. and European manufacturers. This advantage is less today than it was five years ago and is forecast to be still less by 2007. This may allow domestic manufacturers to market more competitive products in the future. European manufacturers are forecast to remain at a significant disadvantage in this area, however.

TECH-31. Where do you see product and process technology leadership currently and in the future? (consider both manufacturers and suppliers)

Scale: 1 = technology leader
3 = neither technology leader nor follower
5 = technology follower

	Mean Response	
Countries	**Today**	**2007**
Product Technology		
Japan	1.6	1.6
United States	1.9	1.8
Western Europe	2.3	2.1
Korea	3.9	3.0
South America	4.7	4.2
Eastern Europe	4.8	4.0
Process Technology		
Japan	1.2	1.5
United States	2.2	1.8
Western Europe	2.6	2.4
Korea	3.5	2.8
Eastern Europe	4.6	4.1
South America	4.6	4.1

Selected edited comments

- The United States and Western Europe will continue to have labor concerns that will inhibit process improvement.

Discussion

Panelists rate Japanese manufacturers the highest in both product and process technology currently and forecast that they will retain a leadership position in 2007. The United States and Western Europe are rated second and third respectively in both product and process technology, and are forecast to retain those positions in 2007. The product-technology position of the Japanese manufacturers is forecast to be unchanged through 2007, whereas the process-technology position is forecast to decrease slightly. The product-technology position of U.S. manufacturers is also forecast to be almost unchanged in that time frame, whereas the process-technology position is forecast to improve.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of process technology in the United States in 2007. Manufacturers forecast a rating of 2.0 whereas suppliers forecast 1.6.

Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey. Results of the current and previous two surveys are shown in the following tables. Korea was not included in the 1994 Delphi VII survey.

	Product Technology					
	1994 Delphi VII		1996 Delphi VIII		1997 Delphi IX	
Countries	1993	2003	1995	2005	1997	2007
United States	2.0	1.7	2.1	1.7	1.9	1.8
Europe						
Eastern	4.5	3.8	4.9	4.4	4.8	4.0
Western	2.4	2.1	2.5	2.3	2.3	2.1
Japan	1.6	1.6	1.5	1.6	1.6	1.6
Korea	n/a	n/a	4.2	3.4	3.9	3.0
South America	4.1	3.8	4.7	4.4	4.7	4.2

	Process Technology					
	1994 Delphi VII		1996 Delphi VIII		1997 Delphi IX	
Countries	1993	2003	1995	2005	1997	2007
United States	2.3	1.8	2.3	1.8	2.2	1.8
Europe						
Eastern	4.5	3.8	4.7	4.2	4.6	4.1
Western	2.6	2.4	2.9	2.6	2.6	2.4
Japan	1.5	1.5	1.3	1.5	1.2	1.5
Korea	n/a	n/a	3.9	3.4	3.5	2.8
South America	4.1	3.7	4.6	4.3	4.6	4.1

There is very clear agreement between the three surveys for product and process technology.

Strategic considerations

Technology will play an increasingly important role in the automotive industry in the next decade. Some of the challenges facing the industry are requirements for shorter development cycle time, reduced product and development cost, safety and environmental challenges, and increasing globalization. The manufacturer that best manages technology will best manage the above challenges. Technology will play a key role in each of these areas.

Panelists rate Japanese manufacturers as having the best product and process technology currently and forecast that they will retain this leadership role in 2007. The ratings for the United States for 2007 are very close to the Japanese in both areas. This should allow domestic manufacturers and suppliers to compete more effectively in global markets.

It must be remembered that these forecasts are for the aggregate industry in each area. In reality, performance should be represented as a "bell curve." Significant variations can occur between companies within a given region.

One of the greatest challenges facing the United States in the next decade is developing a workforce that can deal with technological change. Education in universities in the United States is as good as any in the world. This should assure a competent supply of engineers, scientists and computer specialists to the industry. Education in primary and secondary schools, however, is not world class. It will be a significant challenge to the automotive industry to find personnel for manufacturing jobs that are equipped to deal with rapidly changing technology. The burden may well fall on the industry to train the required personnel.

The United States excels in many areas of technology, including computers and aerospace. Programs such as the PNGV are opportunities to transfer this technology to the automotive industry.

TECH-32a. Using current vehicles as a baseline, what is your expectation for the change in vehicle design efficiency in the next decade.

Scale: 1 = dramatic improvement 3 = unchanged 5 = dramatic degradation

Vehicle Design	Mean Response
Noise reduction efficiency (dB reduction/mass added)	2.0
Stiffness efficiency (stiffness/mass)	2.1
Packaging efficiency (interior vol./plan view area)	2.1

Other Responses:

High mileage function - 4

Mass efficiency - 2

Overall mass - 1

Safety packaging - 2

Selected edited comments:

- Aluminum extrusions will play a large role.
- Continuous improvement, smarter design tools, benchmarking and better internal communications infrastructures will support continued improvements in design efficiency.

Discussion

Panelists forecast moderately improved design efficiency for packaging, vehicle stiffness and noise reduction in the next decade.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was asked for the first time in the 1996 Delphi VIII survey. Results of the two surveys were quite similar.

Strategic considerations

An increased use of computers and better simulation models can assist in bringing about the forecast improvements in design efficiency. Modeling techniques can provide for increased stiffness and reduced noise without the traditional penalty of increased mass. Likewise, modeling can allow increased interior volume without increasing the exterior dimensions of the vehicle.

With the forecast for increased fuel economy requirements it will be imperative that, as the vehicle is improved in the areas of stiffness, noise reduction, and packaging, the mass of the vehicle is not allowed to increase. In fact, the challenge will be to reduce mass while improving other attributes of the vehicle.

It would probably be useful to generate a set of efficiency indices representing a number of key vehicle factors. This would help with the comparison of various designs. Some companies use these indices internally, but they are not widely used in the public literature.

TECH-32b. What is the first order body beaming and torsional frequency of both a typical current midsize and a luxury vehicle? What will it be in 2007?

	Median Response		Interquartile Range	
	Body Beaming	Torsional Bending	Body Beaming	Torsional Bending
Current				
Midsize:	23 Hz	23 Hz	20/23 Hz	20/25 Hz
Luxury:	23 Hz	25 Hz	22/24 Hz	22/27 Hz
2007				
Midsize:	25 Hz	25 Hz	24/27 Hz	22/27 Hz
Luxury:	26 Hz	27 Hz	23/28 Hz	23/30 Hz

Selected edited comments

- Frequency should not change dramatically unless mass distribution in the vehicle is altered or the stiffness is significantly changed. The latter is not likely with a push for lighter weight. The former is not likely with the need for increased passenger comfort. I do not anticipate a change in frequency.
- I expect 30 percent improvement.
- Systems will become stiffer and lighter.

Discussion

Panelists forecast that body beaming and torsional bending frequencies will increase about two Hz for midsize and luxury vehicles by 2007.

Manufacturer/supplier comparison

There are not enough responses from suppliers to make a statistical comparison.

Trend from previous Delphi surveys

This question was not asked in previous Delphi forecasts.

Strategic considerations

Increased body beaming and torsional bending frequencies indicate a more rigid body structure. A more rigid body structure provides improved ride and handling characteristics and reduced noise and vibration. Panelists forecast a modest increase in body beaming and torsional bending frequencies by 2007. It is likely that these forecast increases would be greater without the known constraint of improved fuel economy requirements.

Most current vehicles have been designed to be considerably more rigid than in the past. It appears that the greatest rate of change is behind us.

Strategic considerations from TECH-32a apply here also.

TECH-33a. What percentage of vehicle engineering is done using math and computer-based tools (CAE) currently and will be in 2002 and 2007? (NOTE: This question does not refer to tools used in computer based design (CAD), but rather to tools used in, for example, crash simulation, stress analysis, etc.)

Percent of Vehicle Engineering Utilizing Computer-Based Tools					
Median Response			Interquartile Range		
Current	2002	2007	Current	2002	2007
30%	50%	70%	30/40%	46/60%	65/80%

Selected edited comments

- As databases increase, simulations will improve.
- As the workforce changes over to engineers trained in computer design and analysis, companies will be able to realign the product development from cut-and-try to a more analytic design-and-verify.
- CAD is at a critical point. The next three to four years will see a big change, affecting CAE positively.
- Computer analysis is accurate, quicker, and costs less than conventional testing. Initially, models required test verification. As the database grows and model confidence increases, there will be less need for verification testing.
- Computer design aides are currently used more for design direction than absolute design. Substantial increases in computer-based engineering will require better validation and verification of computer models such that results do not always have to be validated with actual hardware. Furthermore, overturn in the aging workforce will increase acceptance of computer-based engineering methods.
- Cost of testing will drive computer-based analysis higher.
- FEA productivity has gone up over 500 percent since 1990.
- Growth will be in manufacturing simulation, ie. "virtual manufacturing", to complement CAD/CAE/FEA tools. Massive parallel computing will enable near real-time simulation of design and manufacturing by 2002. Visualization will begin beyond 2002-2007.
- I believe that only a certain level is possible in the near future.
- In order for the use of simulation and analysis tools to become more effective, component design information and technical knowledge will have to be made more available and easy to access in the OEM/supplier information technology infrastructure.
- Math- and computer-based tool use continues to increase. Virtual reality work, currently in its infancy, has the potential to cause shifts in the way styling is done. This will cause benefits in computer-based product/manufacturing design.
- Modeling done today is limited. It will ultimately reduce design cycle the most.
- Numerical values in this area are extremely hard to verify, as it is the accuracy of the models that are generated that need finite measurement.
- Soft tooling will be eliminated. Math modeling input will become more "true" so that simulation will become more accurate.
- The critical factor is developing a database which shows good correlation between computer

model results and actual test data. Also the interpretation of the data is critical.

- The use of computer-based tools for complex automotive system simulation, analysis, design, integration and testing will increase dramatically.
- There is a risk that as engineers become dependent upon simulations, they will lose understanding of the physical phenomena that they are analyzing.

Discussion

Panelists estimate that 30 percent of vehicle engineering currently uses math- and computer-based tools and that this will increase to 70 percent by 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Strategic considerations

The forecast increase in math and computer-based tools will decrease product development time and reduce cost and may improve quality and other performance factors and reduce vehicle weight. Some of the specific potential benefits of increased utilization of math- and computer-based tools are:

- reduced number of prototype components and vehicles
- reduced weight through optimization of material usage
- reduced lead time by means of reduced design time, reduced testing requirements and direct interface of design and manufacturing tools
- improved quality as a result of increased analysis of strength, fit and function
- more optimum design at first prototype build

New software and improvements in current software will facilitate the forecast increase in the use of math- and computer-based tools. Current software is expected to become more user-friendly. Manufacturers and suppliers will be challenged to keep abreast of the latest developments in this area and to assure that personnel are adequately trained to maximize the potential of this technology.

Some of the development time bottlenecks that currently reside with the manufacturers may be reduced substantially with modern CAE tools. This could place a significant added burden on suppliers at a time when they are already under great stress. This is a critical area for all in the industry to track closely.

TECH-33b. With the advent of improved simulation and analytical tools the number of physical prototypes may be reduced in the years ahead. Using 1997 as a baseline, what percentage reduction in physical prototypes do you expect by 2002 and 2007?

	Median Response		Interquartile Range	
Physical Prototypes	**2002**	**2007**	**2002**	**2007**
Full vehicle	20%	40%	15/25%	30/50%
Chassis/suspension	20	30	15/20	25/40
Powertrain	15	30	10/20	25/30
Seat	20	30	15/25	20/40

Other Responses:

Electronic – 2002: 40%; 2007: 80%

Electronic systems – 2002: 60%; 2007: 90%

HVAC – 2002: 25%; 2007: 50%

HVAC – 2002: 30%; 2007: 60%

Other – 2002: 20%; 2007: 30%

Other – 2002: 30%; 2007: 50%

Packaging – 2002: 80%; 2007: 100%

Selected edited comments

- Common platforms will significantly reduce the need for as many prototypes.
- Fewer complete prototype vehicles will result from better simulation tools and more economic pressures to curtail. The impact on the number of dedicated single-purpose mule vehicles (for focused development) will be less.
- Full vehicle prototypes will reduce about 50 percent from today to 2002 and maybe an additional 25 percent (for a total of 75 percent) by 2007. Chassis, Powertrain and Seat are already at minimum levels.
- Full vehicles for overall vehicle evaluation need to remain at near current levels for tuning and confirmation of concept. However, full vehicles for crash tests will be reduced as crash simulation becomes more accurate.
- In a continuing effort to reduce cost and weight, new material (including composites) will be introduced. I do not think manufacturers will have the confidence to rely on simulation tools, but will prefer to produce prototypes and test them.
- Most reductions will come early as "test-fail-redesign" cycles will be reduced.
- Prototype vehicles will be reduced significantly, mainly because of the short development period. On the contrary, preprototype vehicles will be increased to make development period short.
- Reduction in prototypes will be dramatic for the full vehicle and less for subsystems. Testing will be completed on subsystems and vehicles will be built to insure fit and finish.
- Reductions are not solely due to advances in analytic tools, but also due to the economic necessity of making better use of the prototypes that are produced. Sharing of prototypes

across systems and subsystems will continue to increase.

- Simulated analysis will increase, but correlation to actual consumer usage will take time. The confidence level in predictions will not significantly reduce physical testing, particularly in the areas of vehicle NVH.
- Subjective evaluations of the total vehicle will continue to be a necessity. Tuning issues and confirmation of concept intent will be key issues requiring full vehicles. Crash test simulation however will increase significantly if there is proven to be good correlation.
- The companies that we use as benchmarks for the industry build many prototype vehicles to insure fit and finish, comfort of ride, etc. I foresee no change in the number of full vehicle prototypes. However, I do see a change in the supplier industry to increase the use of standard assemblies to ultimately reduce the cost of the final prototypes.
- The major improvement will come in body and chassis simulation for manufacturing and fitup.
- The number of full vehicle prototypes required by GM has risen dramatically over the last five years or so. This will, I'm sure, start to decline as simulations continue to improve.

Discussion

Panelists forecast that full vehicle prototypes will decrease by 40 percent and some component prototypes by 30 percent by 2007 as a result of improved simulation and analytical tools.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Strategic considerations

The forecast reduction in the number of prototypes required will reduce development costs and personnel requirements. As noted in panelists' comments, however, confidence in the correlation of analysis and physical testing must be assured in order for this change to occur.

There are obviously some mixed views within the industry on this topic. Clearly, if a given manufacturer or supplier can reduce substantially the need for prototypes without compromising the final design, they could achieve significant competitive advantage. All companies are not equal in this area, and the best will become the benchmark for the others. Today, it is increasingly not "how hard you work" but "how smart you are" that will determine your success.

TECH-34. Considering the recent Big Three effort to standardize electrical connectors, under the auspices of USCAR, what additional components are likely candidates for standardization by 2007?

Responses:

A/C compressors (3 responses)

AC systems, emission components

Airbags (3 responses)

Alternators (3 responses)

Audio components, switches, rearview mirrors

Basic "commodity-like" fluids, and common service parts (wiper blades, etc.) make good candidates for standardization.

Brakes, lights

CAD systems; material specs

Can buss—communications, global testing—environmental, global standard on communications (wireless)

Catalytic converters, radiators, A/C condensers, and numerous other "noncore" components—this will happen because OEMs will outsource this activity to the low-cost supplier, and one way for the supplier to reduce cost is to standardize.

Communications protocols, cell phone docking connection, wheel speed sensor outputs

Cylinder bore diameter (pistons, rings, etc.)

Electrical buss/diagnostics, data buss, driver interface message content

Electronic keys, seat belts

Engine controllers

Engine sensors, motors, jacks, other noncompetitive components

Exhaust hoses, brake systems components

Fasteners in general (11 responses)

Fittings

Fluid lines (brake, vacuum, etc.)

Fuel filter

Fuel injectors, hoses, air conditioners.

Fuel line connectors (2 responses)

Fuel lines (3 responses)

Fuse boxes, window mechanisms, seat tracks and motors, air springs for hatches and hoods, wheels (bolt patterns and pilot holes), latches, door locks and mechanisms

Gas caps (4 responses)

Hoses (3 responses)

Lighting (2 responses)

Mechanical attachments

Microprocessors and self-diagnostic units; sensors for safety and basic performance functions; materials specifications; instrument and control layouts; vehicle location transponders

Motors, crash structures (side doors, etc.)

Nuts, bolts, heat exchangers, hoses, HVAC subsystems, radios, wiper systems, starter motors and most other components provided by suppliers

P/S pumps

Paint

Pistons/system components, suspension components—pumps/valves, springs, etc.

Plastic materials, battery sizes, maybe some test and validation procedures

Power steering pumps(3 responses), shock absorbers

Radio size, which is almost there today, miscellaneous other components like generators, AC compressors, power steering pumps, several interior items, coat hooks, grab handles, cup holders, etc.

Retractors

Safety items

Sensor output formats—will allow them to be more "commodity-like"

Sensors, actuators, controllers

Shipping containers, engine sensors, battery, relays

Thermostats, wheel nuts, some light bulbs

Tires, spark plugs, bearings, oil filters, etc., i.e., things the customer cannot see, touch, or feel and do not add customer value!

Vehicle networks

Vehicle software operating systems, electric motors

Windshield washer blades/paints; adhesives/metals (alloys) diagnostic ports/connections

Wire, multiplexing modules

Discussion

Panelists have noted a number of items that are candidates for standardization by 2007. The greatest number of responses was for fasteners.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This comparison is not made for open-ended questions.

Strategic considerations

Meaningful cost savings are possible by standardization of components. Savings accrue through reduction in engineering and testing, release and tracking of new parts, tooling, handling of multiple parts in the assembly plant, and warehousing of service parts.

Cost avoidance may also be possible by reducing the potential for build errors in the assembly plant.

Standardization is particularly beneficial when it is transparent to the customer. This is often the case on simple components such as fasteners, but may also be true of complex systems such as suspension systems. How many seat belt designs are needed in a vehicle manufacturing organization or the automotive industry? How many are there? A little attention to this important area can pay large financial dividends and consequently will be pursued by the manufacturers to reduce cost. The implications for the supply base are substantial. Of course, even though this in many ways is common sense, it will require considerable effort to implement. The U.S. Council on Automotive Research (USCAR) has formulated a group called the Strategic Standardization Board to oversee and encourage this activity within the Big Three.

TECH-35. Please rate your organization's current state of implementation of "systems engineering."

Scale: 1 = excellent/high 3 = moderate 5 = poor/none

Systems Engineering	Mean Rating
Management's use/embrace of systems engineering	2.9
Middle/senior management's understanding of systems engineering	3.1
Effectiveness of systems engineering in your organization	3.2
Number of systems engineers in your organization	3.4

Selected edited comments

- Everyone has their own definition of systems engineering. Middle management is particularly reluctant to change; the turf is still defended.
- I'm sorry to report, the systems trend is just beginning in our organization, a little late to become a world class global supplier.
- Management is trying to make everyone behave like a systems engineer. No separate systems engineers are being added to the organization.
- Many systems engineers are that in name only. They are not "practicing" systems engineering in the true sense of the word. There is much learning/paradigm shifting to do yet.
- Systems can affect many different companies or modules with one coordinator. Modules can have parts of many systems in a single hardware assembly.
- Systems engineering has various and broad definitions. The auto industry has not matured in its understanding of how to effectively design complex and highly interactive systems, as the aerospace industry has. Systems engineering is not just being able to supply all of the components, but to effectively analyze and manage the system design tradeoffs.
- The "strong systems/requirements engineering" concept has never been fully supported by upper management and is dying a quick death, especially with the advent of VLEs.
- The understanding of systems engineering comes from its use. Current management grew up in an era when systems engineering wasn't used for their jobs. As management turns over with those who have used systems engineering it will gain solid, broad-based support from senior management.
- This is another key to efficiency—understanding where "your product" fits into the scheme of things; understanding what "comes in" and "what goes out" of the engineers component; who the customers and suppliers are and what the deliverables are.

Discussion

Panelists rate their organization's current state of implementation of "systems engineering" as moderate.

Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers for the areas shown in the following table.

Systems Engineering Implementation		
	Rating	
	Mfr.	Supp.
Effectiveness of systems engineering in your organization	2.8	3.4
Number of systems engineers in your organization	2.9	3.7

For the areas for which there is a difference, manufacturers rate effectiveness and number of systems engineers higher than do suppliers.

Trend from previous Delphi surveys

This question was first asked in the 1996 Delphi VIII survey. The results of that survey are compared to those of the current survey in the following table.

	Mean Rating	
Systems Engineering	1996 Delphi VIII	1998 Delphi IX
Management's use/embrace of systems engineering	2.6	2.9
Middle/senior management's understanding of systems engineering	2.7	3.1
Effectiveness of systems engineering in your organization	3.0	3.2
Number of systems engineers in your organization	3.1	3.4

Results of the two surveys are similar, with a slight trend toward poorer implementation of "systems engineering" in the current survey.

Strategic considerations

Systems engineering has been used effectively in the aerospace industry for many years. The formalization of this process is newer to the automotive industry. The basic concept consists of defining customer requirements and rolling these requirements down to specific component specifications. An integral part of the process is to assure that all systems of the vehicle are compatible and work together to meet vehicle requirements.

It is the authors' observation that Japanese manufacturers have done a superior job of "systems engineering". Domestic manufacturers have improved significantly in the last ten years, but still need to improve further. From panelists' ratings and comments, some organizations may in fact be moving away from systems engineering. By so doing, quality, cost and customer satisfaction may be jeopardized.

Suppliers of components have a stake in systems engineering in that the supplied components may work well as an individual component, but not function adequately as part of a total system. This can result in late changes to the component, or in the worst case, a vehicle that does not

perform as expected in the hands of the customer. It is imperative that component suppliers understand the system in which their component is to be used and other systems that may affect their component. This understanding should be developed in conjunction with the vehicle manufacturer.

A key comment stated that there are many different definitions of systems engineering; this breeds confusion in the industry. Clearly, it is imperative to improve overall competency in all facets of systems engineering.

TECH-36a. With the increase in design and development of components and systems by suppliers, what are the major supplier/OEM technical issues confronting suppliers and OEMs?

Responses:

Communication (16 responses)

CAD/CHE/PIM integration between OEM and suppliers (7 responses)

Communication, validation of end products, liability

Communication—working with common, up-to-date design environment

Compatible data systems, transferring data

Easier exchange of technical information electronically between supplier and OEM

Geographical location, common engineering tools and methods

Global OEMs achieving common design systems

Proper communication and follow-up

Rapid and effective communication of design specifications as well as effective sharing of design concepts/data

Technical interactions between suppliers and the multiple D&D and manufacturing sites of globally oriented OEM organizations

Definition of requirements (6 responses)

Accurate specifications from OEMs

Agreements on specs and testing

OEMs are not prepared to give sufficiently detailed sets of requirements to suppliers because they worked internally using meetings and constant feedback in place of developing specifications up front.

OEMs providing technical information early in the development cycle

Performance to agreed specifications

Understanding the OEM requirements

Definition of responsibility (7 responses)

Accountability

Defining roles and responsibilities that "fit" each scenario

Design control including documentation, ECNs, and changes. When there are changes needed (or problems), who will take final responsibility?

Final design control

First tier supplier taking responsibility for final product (even if some components are outsourced).

Responsibility and accountability for technical work

Who is responsible for design/test/performance warranty

Financial (13 responses)

Ability for suppliers to maintain margins with added overhead

Adding to the increased costs that will be necessary to conduct R&D demanded by the auto industry while supplying low-price products

Cost (4 responses)

Cost reduction (2 responses)

Resources, people and facilities

Trade-offs of cost vs. requirements

Who is paying for long-term development that is needed.

Who will pay for engineering, who pays for warranty, margin expectations, engineering service firm role

Will the OEMs be willing to pay higher prices for designed/developed components/systems?

Liability (2 responses)

Liability

Product liability partition between supplier/OEM

Miscellaneous (17 responses)

Applications engineering

Change management process

Commonality among competing suppliers.

Coordination problems

Globalization (fuel quality globally); standardized engine management instrumentation does not exist.

Incorporating production plant/manufacturing considerations

Innovation

Interaction of suppliers to optimize

Not-invented-here syndrome, absence of common standards

Prompt and effective resolution of problems

Providing the supplier with the standard components to use as part of a system, without limiting sourcing and design abilities

Resource reallocation

Sharing basic designs and manufacturing to allow cost reduction, yet being able to adapt to specific needs

Traditional OEM specifications will be challenged by the suppliers via new tools (simulation and analysis) and material substitution.

Weight reduction

Weight reduction, reduced noise, improved fuel economy

When is an assembly module an assembly module; it's different for all OEMs.

Ownership of intellectual property (4 responses)

Confidentiality

Ownership of intellectual property

Sharing of advanced technology so that we can all plan, but still protect the intellectual property of each (OEM and supplier) in a fair way. Suppliers are justifiably concerned that if they share their future technologies with us during advanced programs that we will give it away to the low bid supplier for the volume production.

Who owns the design technology

Quality (4 responses)

Design/quality assurance and evaluation for function (for the design life of the component/vehicle subsystem).

Quality among competing suppliers

Quality control (3 responses)

Quality/reliability (2 responses)

Supplier Capability (12 responses)

Competent engineering staff

Deficiency in technical competence of suppliers

Maintain necessary technological advancement

Obtaining equipment and training personnel to perform all the necessary tests demanded by OEM

Proven/capable organizations to execute

Rate of change in responsibility level at supplier; need to expand skill base of supplier organization

Skilled labor, engineering skills—talent, long-term experience—too much people movement

Supplier firms' ability to attract top talent, managing growth.

Suppliers are stretched too thin (technically)

Suppliers maintaining R&D capability in face of cost reduction pressure

Suppliers must develop the technical capability to truly engineer their components to function in the systems in which they are integrated as well as in the total vehicle environment.

Who will be the technical experts in the future? What will the OEMs retain as core competencies?

Systems engineering (19 responses)

1) "Interface" between components and systems; 2) system knowledge

Absence of systems engineering understanding. Functionally organized organizations which can't manage tradeoffs across functional lines.

Development of a system specification on a timely basis. Maintaining a plan. Smooth communication of plans and coordination of efforts. It is more management of people and information than "hard-design" issues.

Good up-front specifications

Integration of components into vehicle designs will be the largest technical issues.

Integration without mistakes

Interface definition and requirement definition

Interface of systems within the total vehicle.

Interface standardization

Interfacing with adjacent systems/supply teams

OEMs do not understand the relationship between their system function and all vehicle attributes, especially interrelated attributes.

Specifying exactly what the components must do using systems-engineering techniques is essential. However, we are not yet as precise as we need to be to take the developed components and have them work perfectly when you plug them in.

Suppliers acquiring system engineering capability and tools. OEM downsizing existing system engineering in-house organizations.

Supplying nontraditional modules (cockpit whole, corners, etc.) that violate the traditional break-up of work between traditional engineering groups (who writes the requirements?)

System engineering capability

The collection and exchange of information describing the "systems" that the suppliers and manufacturer are building.

The complete vehicle is made up of many systems and the OEM needs to maintain the responsibility for the complete vehicle.

Total system capability, modularization, simulate and validate with software

Trends and wants by the customer. Many benchmarking and surveys have been completed to establish trends. QFDs have been completed based on the data. Designs are created based on all the inputs. The information and design are proposed, accepted at low levels of the organization and rejected by higher management, due to the unknowns of managers.

Testing (3 responses)

Self validation and OEM test and validation processes

Testing equipment/knowledge

Testing—similar components have to meet different test programs for different OEM's, delineation of design responsibility between OEM and suppliers.

Timing (4 responses)

Development lead time vs. final specifications

Development timing concerns—maintaining deadline

On-time delivery

Timeliness

Transfer of responsibility and technology (3 responses)

Transfer of responsibility and technology (2 responses)

Transfer of systems responsibility to the supplier without the OEM duplicating the efforts

Trust (3 responses)

Demonstrated performance which will provide the trust foundation for the OEM to "release" control of the design and fully redeploy the people. In addition, the supplier must pick up the responsibility but not increase the selling cost.

Eliminate shadow engineering by the Big Three OEMs, building trust and integrity on both sides, i.e., OEM and suppliers.

Trust

Discussion

Panelists have noted a significant number of major supplier/OEM technical issues confronting suppliers and OEMs. The most frequently mentioned issues were in the areas of systems engineering and communications.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Strategic considerations

Panelists have noted many significant supplier/OEM technical issues confronting suppliers and OEMs. The most frequently mentioned issues are in the area of systems engineering.

Resolution of these issues is critical to the timely production of quality vehicles that meet customer expectations. Many of the issues also reflect on the financial health of suppliers, who are an integral part of the automotive industry. Resolution will require a concerted effort between manufacturers and suppliers.

We hope readers of this question will study the responses carefully. They provide rich food for thought and discussion. This is certainly an industry with much to do in the manufacturer/ supplier connection.

TECH-36b. What are your recommendations to rectify the above issues?

Responses:

Assignment of responsibility (3 responses)

Give the supplier more design responsibility and control.

More responsibility to the suppliers

OEMs must retain control of major vehicle core competencies (engine, suspension, etc.).

Communication (8 responses)

Adopt a common system for data; use the same format

Better coordination between suppliers and OEMs

Continue development of common database format

Electronic linkages

Establishing an "information age" communications infrastructure to minimize the time and distance factor. Also, effective CAD data translators are required to make different CAD systems compatible.

Improved communication of objectives (long-term ones)

Industry standardization of CAE software through AIAG or other

Standardized data systems for allowing exchange of information much as has already been done for exchange of some design information. Needs to be coordinated through the SAE, AAMA, or similar organization.

Definition of responsibility (4 responses)

Definition of requirements

Eliminate developing system from component, first develop system specifications

Firm rule based method to allow trade-offs (e.g., dollars per feature; suppliers will naturally partnerup; negotiated between OEM and supplier by contract)

On-site supplier engineers to develop specifications with OEMs

Education (2 responses)

Top management education; OE commitment and recognition of the value of these services.

Training in systems engineering concepts at the corporate level as well as within our engineering schools

Liability (2 responses)

Change in liability laws.

Modification of product liability laws.

Miscellaneous (9 responses)

"Do it"...make it work; grow the business/relationships.

Early sourcing agreements

Focus on these issues

Have the auto industry involved to the extent that they really understand the costs and needs of new product R&D. This will require in-house and university sponsored R&D efforts and the establishment of research houses with the technical staff competent to conduct such work.

Keiretsu

Larger suppliers; OEMs must set aside resources for commonality

Practice makes perfect. Jump in and get some learning cycles under our belt.

Scenario-based planning for design/evaluation and production implementation aimed at modularization systems and component standardization

Top management direction and implementation

Quality (1 response)

Expanding the QS-9000 model beyond a company's walls to include the Joint Development Team's operation.

Supplier capability (6 responses)

1) Suppliers must work inside; 2) suppliers must hire more engineers – they have a problem balancing workload.

Maturation of supplier-base in general

More investment by suppliers

More R&D, stable workforce, less "job shopping"

Suppliers will need to increase resident engineering support at OEM facilities.

Tier one suppliers need to increase facilities

Systems engineering (9 responses)

Additional systems engineers at the OEMs bridging traditional functional boundaries

Develop and empower systems engineering-led cross functional product development teams.

Develop specifications and performance parameters earlier and stick to them.

More emphasis on systems engineering

More systems engineering

OEMs must get further refined systems engineering techniques to better specify performance expectations of components and systems. Suppliers need to partner with solid engineering organizations to build expertise as well as work closely with OEMs to gain the profound knowledge.

OEMs need systems-interface engineers.

Specifications and standards

Systems engineering and QFD approach to design

Team building, partnership (13 responses)

Better management, positive relationships with OEMs

Enable more product- and process-oriented teams, develop cooperative technical development relationships with strategic suppliers and universities, work towards common industry communication and "interconnection" standards—major obstacles to overcome center around breaking the current "that's the way it is done in the auto industry" paradigm in middle and upper management.

More "team development" efforts

More open dialogue between OEMs and suppliers (dialogue today is more monologue (OEM to suppliers)

OEM and supplier must share in the risk and benefits—now each is trying to outdo the other!

OEM recognition of long-term suppliers

Open relationships

Pay for performance

Supplier buy-in as a partner in the overall development

Supplier/OEM alliances—support international standards

The supplier and manufacturer must function as a team with a sharing of success and failure as motivation.

Time and establishment of "real" partnerships

Work as one team in one location.

Testing (4 responses)

Collaboration of testing and prototype builds

Develop and implement standard instrumentation

Outsource to organizations specializing in required product verification

Testing—SAE (or some similar organization) develops standard test sequences, design responsibility, earlier involvement

Trust (4 responses)

For movement toward mutual trust (soft issue but important), involve the CEO, senior, and midlevel management and make the requirement part of the performance review process and reward.

Improved long-term supplier relations, increase trust and reliance, with less threat of always going to lower cost suppliers without technical capability.

OEMs must relinquish control over component design and allow suppliers to provide black boxes and provide as much up-front vehicle information as possible.

OEMs will have to trust the supply base, as first tiers will have to trust their suppliers. OEMs are often quoted as partnering with suppliers, but that seems to be just a part of the story.

Discussion

Panelists have noted a number of suggestions for addressing major supplier/OEM technical issues. The most frequently noted were in the areas of team building and partnership (13 responses), systems engineering (9 responses) and communications (8 responses).

Manufacturer/supplier comparison

This comparison is not done for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Strategic considerations

The considerations noted in TECH-36a apply here also.

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TECH-37. Please forecast the materials content change in percentage for the average North American-produced passenger car for 2002 and 2007, given the indicated CAFE scenarios. Leave blank any materials with which you are unfamiliar. (Use plus and minus, e.g., +5 percent, -3 percent etc.) Please reference all percentage changes to base year (1995).

		Median Response			Interquartile Range		
Materials	**1995***	**2002**	**2007**	**2007**	**2002**	**2007**	**2007**
		27.5 mpg	**30 mpg**	**35 mpg**	**27.5 mpg**	**30 mpg**	**35 mpg**
Steel	1782 lbs	-5%	-10%	-10%	-5/-2%	-10/5%	-20/-6%
Cast iron	389	-5	-10	-18	-11/-5	-20/-7	-30/-10
Plastic/composite	245	5	10	15	5/10	5/15	10/21
Aluminum	195	5	10	17	5/10	6/20	10/30
Rubber (including tires)	139	0	0	0	-1/0	-3/0	-5/0
Glass	94	0	0	-1	-1/1	-4/1	-10/1
Copper	45	0	-1	-2	-3/0	-5/0	-6/0
Zinc (include coatings)	33 **	0	0	0	-2/1	-2/0	-2/0
Powdered metal	29	5	7	10	1/10	2/15	2/19
Magnesium	6	10	10	20	2/50	5/65	9/95
Ceramics	n/a	1	2	3	0/5	0/5	0/10

* **Source:** Ward's Automotive Yearbook, 1996 and **Ward's Automotive Yearbook, 1993.

Selected edited comments

- Consider the following assumptions: adaptation of high strength steel chassis, other structural components utilization of aluminum and plastic and moderate reduction in the use of cast-iron components.
- I expect aluminum and plastic to gain significantly with attempts to reduce weight.
- Magnesium is going to be the big winner, as several powertrain components, including items as large as automatic-transmission cases, have a high probability of being produced in magnesium if new processes can bring down the cost of the raw magnesium material.
- Material cost and legislation will drive the rate of material changes.
- Powdered metal usage will increase for products like con-rods, small gears, etc.
- Recyclability may require use of easily recycled materials like steel.

Discussion

Panelists forecast reductions in the use of cast iron and steel of 18 percent and 10 percent respectively by 2007 for a CAFE standard of 35 mpg. On the other hand, use of magnesium, aluminum and plastic/composite is forecast to increase by 10 to 20 percent in the same time frame. Responses for this question are highly dependent on the CAFE level assumed. For example, for 2007 the use of cast iron is forecast to decrease 18 percent for a CAFE of 35 mpg, but only 10 percent for a CAFE of 30 mpg.

Manufacturer/supplier comparison

There are not enough responses for ceramics to make a statistical comparison. There is no statistically significant difference in responses between manufacturers and suppliers for the other materials.

Comparison of forecast: MAT-22

There is a statistically significant difference in mean responses between technology and materials panelists for the materials and years shown in the following table.

Material Content Change - Percent						
Materials	2002 CAFE =27.5 mpg		2007 CAFE =30 mpg		2007 CAFE =35 mpg	
	TECH	MAT	TECH	MAT	TECH	MAT
Steel	-	-	-9	-12	-14	-21
Aluminum	-	-	-	-	26	51
Rubber	-	-	-1	-4.4	-	-
Zinc	-	-	-1.2	-15	-1.9	-22
Magnesium	29	56	47	99	70	184

In all cases, the materials panel forecasts a greater change, either positive or negative. For zinc and magnesium, the total quantity of material currently used in a vehicle is relatively small. If a change is thought of in terms of absolute weight, a small change in weight can cause a large percentage change.

Trend from previous Delphi surveys

This question was first asked in this format in the 1996 Delphi VIII survey. In previous forecasts, panelists were asked to respond with weight changes in pounds, not percentages. The results for Delphi VII were converted from pounds to percentage changes in the table below. A comparison of the current survey to the two preceding surveys is shown in the following table.

Materials	1995*	Median Response for 35 mpg CAFE		
		Delphi VII 2003	Delphi VIII 2005	Delphi IX 2007
Steel	1782lbs	-18%	-15%	-10%
Cast iron	389	-30	-15	-18
Plastics/Composites	245	31	15	15
Aluminum	195	57	20	17
Rubber (including tires)	139	-5	0	0
Glass	94	-8	0	-1
Copper	45	-18	-5	-2
Powdered Metals	29	17	5	10
Zinc (include coatings)	33**	-14	0	0
Magnesium	6	233	15	20
Ceramics	n/a	n/a	n/a	3

*Source: Ward's Automotive Yearbook, 1996 and **Ward's Automotive Yearbook, 1993.

The results of the current survey and Delphi VIII are in general agreement, with the exception of the forecast for increased zinc usage in the current forecast.

Comparing the three surveys, the trend is towards less of a shift from heavy materials such as steel and cast iron to lightweight materials such as plastics and aluminum. Copper and zinc forecasts went from significant reductions to a small change for copper and a significant increase for zinc.

Strategic considerations

Forecasts for material changes for aluminum, magnesium, plastic, steel and cast iron are highly dependent on the assumed level of CAFE. The passenger car CAFE standard of 32 mpg forecast in TECH-3 is between the level assumed in the two scenarios for 2007 in this question. Higher CAFE standards will accelerate the move to lightweight materials.

Higher CAFE standards have been forecast for some time, but have not yet been implemented. As CAFE standards are delayed, so also will the large-scale move to lightweight materials. Vehicle affordability is already a problem, and manufacturers are very reluctant to add cost for materials that are not required.

In many cases the move to lightweight materials requires a long lead time. Aluminum cylinder blocks are an example of such a case. Some manufacturers have made the move to aluminum cylinder blocks in anticipation of higher CAFE requirements, to meet gas-guzzler requirements or to improve vehicle handling.

Many innovative design changes have been recently implemented to reduce the amount of steel in the body of a vehicle. These changes will continue, largely through increased use of computer modeling, high-strength steel and tailor welded blanks, reducing the incentive to change to more expensive lightweight materials such as aluminum. Also, it is imperative to consider manufacturing issues when considering materials.

Recycling may play a greater role in future material selection. Many plastic materials are difficult to recycle, and may be limited in their future use.

Clearly, the material competition can be expected to continue and even increase in intensity. Today, there is just no "forever" for any material in a given application. New materials and manufacturing processes are being developed that could alter the forecast. Consequently, it is important to follow the technology closely.

TECH-38. Indicate the percentage of North American passenger car production for these exterior panels that will be steel, plastic or aluminum. Note: each row for each year should add to 100 percent.

Automotive Components	Median Response 2002			Interquartile Range 2002		
	Steel	Plastic	Aluminum	Steel	Plastic	Aluminum
Exterior Surface Panels						
Doors	85%	5%	3%	80/95%	2/12%	0/10%
Front fenders	84	10	3	74/93	3/20	0/10
Hood	86	5	10	70/90	1/11	3/20
Rear deck	90	3	6	74/95	1/10	1/15
Rear quarter panels	90	2	2	85/98	0/10	0/7
Roof	95	1	2	90/99	0/5	0/8

Automotive Components	Median Response 2007			Interquartile Range 2007		
	Steel	Plastic	Aluminum	Steel	Plastic	Aluminum
Exterior Surface Panels						
Doors	80%	10%	8%	70/90%	5/20%	5/15%
Front fenders	75	15	5	60/90	5/25	1/10
Hood	70	10	14	60/86	3/20	10/26
Rear deck	75	10	10	60/90	2/20	5/25
Rear quarter panels	85	5	5	73/95	0/20	1/10
Roof	90	4	5	80/95	0/10	0/10

Selected edited comments

- I do not see much change in the materials used on exterior panels for North America unless driven by CAFE standards. So I see it as a cost war between the material suppliers. Whoever can drive the cost of their products down the fastest will win. Therefore, if I had to bet on which material gains the most it would probably be plastic, but I thought that before and the steel industry has come roaring back with very competitive high-strength low-cost products.
- Terminal plastic usage–growth restricted by continuous promises for exterior fits and paint quality which don't materialize. Aluminum will definitely increase to provide reasonably efficient mass/cost tradeoffs for the mass challenge.
- This will be affected by the CAFE you mentioned above.
- Unless another fuel crisis or unexpected CAFE regulations shift occurs, I would expect steel to continue as the predominant body exterior material due to low cost, known quality/processing, repair infrastructure, etc.

Discussion

Panelists forecast increased use of plastic and aluminum in all of the listed exterior surface

panels by 2007, ranging up to 15 percent plastic for front fenders and 14 percent aluminum for hoods. Steel is forecast to remain the dominant material for exterior surface panels.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi Surveys

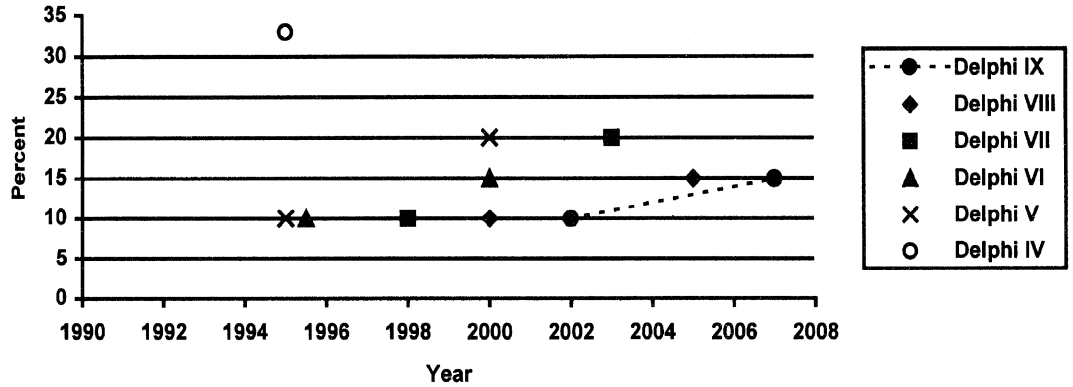
The results for plastics from previous surveys back to 1987 Delphi IV are compared in the following table.

Plastic Exterior Body Component Forecasts											
For year	1995			1998	2000			2002	2003	2005	2007
Date of forecast	1987	1989	1992	1994	1989	1992	1996	1998	1994	1996	1998
	Delphi IV	Delphi V	Delphi VI	Delphi VII	Delphi V	Delphi VI	Delphi VIII	Delphi IX	Delphi VII	Delphi VIII	Delphi IX
Component											
Doors	25%	5%	5%	8%	10%	10%	5%	5%	15%	10%	10%
Front fenders	33	10	10	10	20	15	10	10	20	15	15
Hood	30	10	10	10	15	15	10	5	15	15	10
Rear deck	40	10	10	10	15	15	10	3	15	15	10
Rear quarter	30	5	5	5	10	10	5	2	14	10	5
Roof	15	5	5	3	5	8	4	1	5	5	4

There is general agreement between the current and previous surveys, with the exception of the 1987 Delphi IV survey. In that survey, estimates for the use of plastic body panels were extremely optimistic.

The forecasts for front fenders are shown in the following graph as an example of a typical component.

Plastic Front Fender Forecasts



Results for the current survey are similar to previous surveys, although delayed, with the exception of the very optimistic Delphi IV. Each survey has forecast 10 percent five years out and 15 to 20 percent ten years out.

The forecast use of aluminum in the current and previous surveys is compared in the following table.

Aluminum Exterior Body Component Forecasts								
For year	1995	1998	2000		2002	2003	2005	2007
Date of forecast	1992	1994	1992	1996	1998	1994	1996	1998
	Delphi VI	Delphi VII	Delphi VI	Delphi VIII	Delphi IX	Delphi VII	Delphi VIII	Delphi IX
Component								
Doors	1%	5%	5%	5%	3%	10%	10%	8%
Front fenders	1	5	5	5	3	10	8	5
Hood	2	10	7	10	10	15	15	14
Rear deck	2	5	5	10	6	15	12	10
Rear quarter	1	5	5	5	2	7	5	5
Roof	1	2	2	3	2	5	5	5

The forecast use of aluminum is generally less in the current survey than in the two previous surveys.

Strategic considerations

As noted in TECH-21, one of the driving forces in the use of plastic and aluminum in a vehicle is the need for weight reduction to meet higher CAFE standards. The increased standards have been forecast for many years, but have not come to pass. As a result, manufacturers are reluctant to add cost to the vehicle for these lightweight materials. Steel has, clearly, not been a stationary target in the past few years. Developments in design, material formulation and processing have accelerated in the past years.

Plastic is used successfully in a number of passenger car body panels today and provides benefits of corrosion protection and dent resistance in addition to weight reduction. Plastic body panels on the GM minivans, however, were recently converted to steel to reduce cost.

In the long term, plastic body panels might see some resistance to use because of difficulties in recycling compared to steel. Aluminum body panels are more difficult to attach than steel and are less resistant to dents for a given thickness.

In most cases, body materials are transparent to customers. At least one exception exists, however, with Saturn. Customers have supported the use of plastic fenders and door outers.

TECH-39. What percentage of gasoline-fueled North American-produced passenger cars and light trucks will have gas tanks made from steel or plastic in the indicated years?

Gas Tank Materials	Median		Interquartile Range	
	2002	2007	2002	2007
Passenger Cars				
Steel	50%	25%	40/50%	20/40%
Plastic	50	75	50/60	60/80
Light Trucks				
Steel	60%	50%	50/65%	40/60%
Plastic	40	50	35/50	40/60

Selected edited comments

- Alternate fuels will force a shift to increase the use of noncorrosive, sensitive plastics as well as weight considerations.
- Control of evaporative emissions from the fuel system (now headin.g toward a mandated ZERO emissions requirement) will be a major factor. Weight reduction will be an opposing factor. Materials will be improved so that plastics will be made impermeable and their use will increase. Another possibility may be the development and perfection of collapsible bladders in rigid shells with, perhaps, an additional advantage for plastics because of weight savings.
- Economics will dictate, while plastics costs level out; steel parts will decrease in overall cost.
- Fuel capacity and (empty) component mass favors plastic tanks. With permeation essentially solved, I would expect more and more vehicles to shift to plastic as they go through major redesigns in the years ahead.
- In the worldwide sourcing arena, plastic technology is far more transportable than high-tech steel technology.
- Liquid volume packaging advantages give plastic the edge. Expect plastic to win out when new platforms are executed.
- Packaging availability, particularly in downsized vehicles with 4x4 options, etc., will be a premium and will force special-shape molding of fuel tanks, as well as the need for weight savings.
- The conversion to plastic fuel tanks will be limited only by the ability to integrate the fuel filler into the system. Japanese manufacturers as yet do not feel the need for conversion based on economics as they produce steel tanks at costs significantly less than the domestic OEMs.
- Vehicles will require use of space that can be easily formed only in plastic.

Discussion

Panelists forecast that by 2007 plastic will be used in gas tanks on 75 percent of passenger cars and 50 percent of light trucks.

Manufacturer/supplier comparison

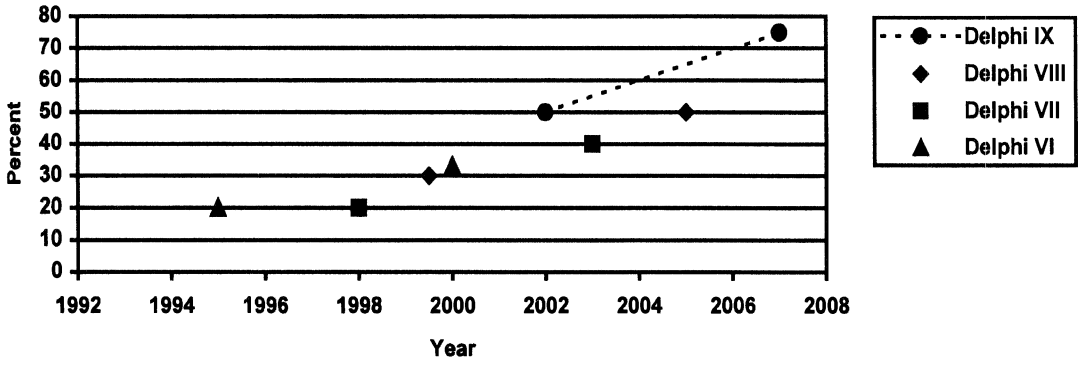
There is no statistically significant difference in responses between manufacturers and

suppliers.

Trend from previous Delphi surveys

The current forecast for plastic gas tanks in passenger cars is compared to previous forecasts in the following graph.

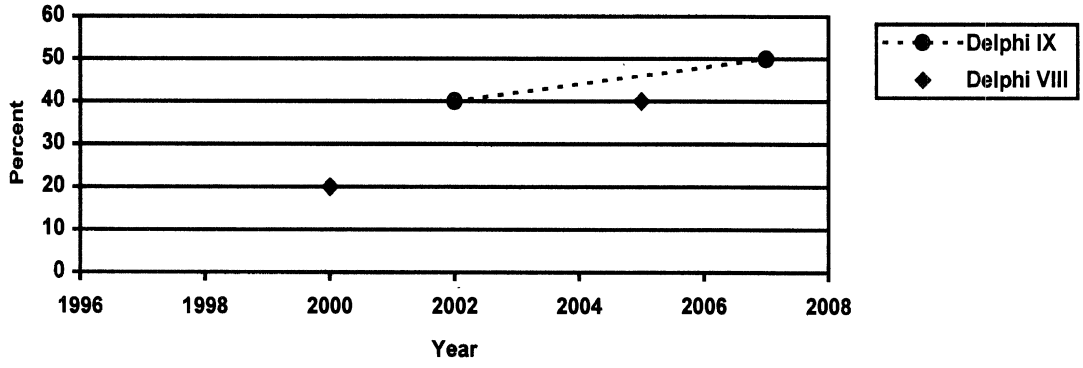
Plastic Gas Tank Forecast - Passenger Cars



The current forecast is on the high side of previous forecasts for passenger cars.

This question covered light trucks for the first time in the 1996 Delphi VIII forecast. A comparison of the two forecasts is shown in the following graph.

Plastic Gas Tank Forecast - Light Trucks



Strategic considerations

As noted in panelists' comments, the ability to form plastic into irregular shapes will accelerate the move to plastic gas tanks in order to maximize fuel capacity. Weight reduction is also an advantage for plastic. An opposing factor is the permeability of plastic, causing evaporative emissions problems. Panelists apparently believe that this problem is or will be resolved.

In the long term, recycling may become a factor influencing material choice. It also should be noted that the traditional tank material, steel, is not standing still. The target that plastic is attacking is moving quickly.

TECH-40. What percentage change in total vehicle weight do you anticipate by 2002 and 2007? Please indicate plus or minus. Please reference all percentage changes to current vehicles.

	Median Response		Interquartile Range	
Vehicle Type	**2002**	**2007**	**2002**	**2007**
Passenger car	-5%	-10%	-10/4%	-15/7%
Light truck	-3	-6	-7/2	-10/5

Selected edited comments

- It depends on the CAFE standard: (1) all domestic manufacturers are projected to fall below the truck CAFE standard and (2) they must develop strategies to create carryback CAFE credit.
- It partially depends on your CAFE assumption.
- Model mix changes are more likely to affect vehicle fleet mass than modest expected mass reductions in the individual vehicles.
- Pressure to reduce mass of light trucks will be more than on passenger cars. Fuel economy and buyer preferences for all-wheel drive, etc., are putting considerable pressure on mass.
- Reduced weight requires more cost. Affordability has become a major issue now and will be even more critical in the future.
- The trend toward larger SUVs and "minivans" fights weight reduction.
- There will be more emphasis on trucks in the near future for weight reduction.

Discussion

Panelists forecast that by 2007 passenger car weight will decrease by 10 percent and the weight of light trucks will decrease by 6 percent.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

In surveys prior to the 1996 Delphi VIII survey, panelists were asked to forecast the percentage change in vehicle weight, without regards to passenger car or trucks. A comparison of the current survey and the past three surveys is shown in the following chart.

		Median Forecast Change in Vehicle Weight						
	Base Year	1995	1998	2000	2002	2003	2005	2007
1998 Delphi IX Passenger Car	1997				-5%			-10%
1996 Delphi VIII Passenger Car	1995			-5			-10	
1994 Delphi VII	1993		-3			-8		
1992 Delphi VI	1990	-4.6		-11.4				

The last four surveys have generally forecast that weight will decrease by 5 percent in five years and 10 percent in ten years.

Strategic considerations

Panelists have forecast for several years that vehicles would weigh less in five- and ten-year periods. In fact, vehicle weight has remained the same or increased slightly in the last few years. Many new vehicles such as the Chevrolet Lumina and the Ford Taurus are actually heavier than the vehicles that they replaced.

In addition to the increasing weight of some vehicle models, more and more customers are buying heavier sport utility vehicles (SUVs) to replace their passenger cars. As stated in TECH-1, with the relatively low price of gasoline in the United States, customers are going to buy the vehicle that meets or exceeds all of their needs.

Increasingly rigid emissions and safety standards are likely to add weight in the future. Also, consumers continue to add features to vehicles, such as cellular phones and CD players.

There are some new vehicles such as the Chrysler Concorde that weigh less than their predecessors. In addition, manufacturers show signs of addressing the weight problem, such as the forecast use of magnesium for the instrument panel support beams on the Cadillac DeVille in 1999. Aluminum is used in more and more engines, also.

Until fuel prices or fuel economy standards increase, it is unlikely that there will be any substantial decrease in vehicle weight, unless of course weight reduction can be achieved at little cost. This may be possible with much better modeling techniques and improved systems-level design capabilities.

It is also important to consider the trade-off between the cost of weight reduction and the cost of improved powertrain efficiency as a means to achieve fuel economy improvement.

TECH-41. Assuming CAFE requirements at 27.5 mpg in 2002 and 30 or 35 mpg in 2007, what is the value today, in current dollars, per pound of weight saved to a vehicle manufacturer? What will it be in 2002 and 2007? Please do not adjust for inflation.

Median Response			
1997 Current Value CAFE = 27.5 mpg	**2002 CAFE = 27.5 mpg**	**2007 CAFE = 30 mpg**	**2007 CAFE = 35 mpg**
$1.00	$1.25	$2.50	$4.00
Interquartile Range			
1997 Current Value CAFE = 27.5 mpg	**2002 CAFE = 27.5 mpg**	**2007 CAFE = 30 mpg**	**2007 CAFE = 35 mpg**
$1.00/1.00	$1.00/1.75	$1.88/3.00	$2.75/5.00

Selected edited comments

- Assuming 1 percent reduction in BSFC = $50.00/vehicle, 10 percent weight reduction ~ 25 percent, BSFC (FTP - 75 cycle) for 3500 lb. Vehicle, 30 percent reduction basis for 30 mpg - 35 mpg ~1000 lbs. reduction ~ $400.00.
- Cost pressures and excess vehicle production will make it very difficult for OEMs to pay for weight savings. It will become a given target, like quality.
- I agree with earlier comments that the answer depends on many factors, including weight class, the individual manufacturer and their product line, market conditions, the regulatory climate and the price of fuel.
- I assume that the manufacturer meets CAFE prior to the mass reduction.
- It definitely depends on where the vehicle is in its weight class, and the possibility of moving to a lower class. These numbers are meant to be averages influenced by the likelihood of changing the weight class.
- It depends on where the manufacturer is relative to CAFE.
- It highly depends on where the vehicle is in its weight class.
- Mass savings have such a compounding impact on the vehicle that it becomes one of the most valuable means to improve fuel economy.
- Obviously, the primary motivator for mass reduction is fuel economy improvement. For a 3,500 lb. car, fuel economy improves around 0.5 to 1 mpg per test weight class (TWC), indicating that the value per pound listed in your initial survey is disproportionately high compared to your dollars per mpg.
- The above assumption assumes that the vehicle meets CAFE target and/or is not near weight class limit.
- The actual willingness to pay is very nonlinear. The value tends to increase at decision points and decrease under "steady state" conditions.
- The assumption is that the motor companies will only pay for weight reductions when they have to in order to meet CAFE mandates.
- The question is impossible to answer in a general way since the value of weight reduction is

highly vehicle-specific! If a specific vehicle runs the risk of entering a higher weight class, the value of weight reduction can be very high. If there is little or no such risk, the value can be very small (≈ 0). Consumers attach value to system (product) attributes, e.g., vehicle acceleration, top speed, fuel economy, etc. Vehicle weight is an example of a system (product) property which influences many system-level attributes but is not in itself a system-level attribute because customers do not experience the vehicle's weight directly. Consequently, the customer's "willingness to pay" for weight reduction depends on how a weight reduction affects those attributes that the customer prioritizes. This will most likely vary from market segment to market segment.

- The real story is that price must come down regardless of what happens with the CAFE regulations. Thus, OEMs are not going to be willing to spend much, if anything, for mass reductions. New concepts are needed that will reduce mass and cost, such as very thin-walled aluminum die castings that reduce the mass to the same as magnesium but actually reduce the amount of aluminum used, resulting in reduced cost.
- The value of mass reduction will be significantly influenced by future CAFE/Guzzler rules. Without this external influence, the value would be very modest, probably no greater than what's already been "baked" into mainstream vehicles.
- The value varies depending on whether or not the vehicle has met its weight target. Vehicle programs would like to have the weight target met at zero added cost. It's only if their vehicle is in weight trouble that they will pay to save weight. Obviously, the lowest-cost changes are used first.
- The values for a weight savings are only to be used to drop to a lower EPA weight class.
- There is no calendar effect on the value of a pound of weight saved, and only limited effect relative to the CAFE level. It is all relative to how close a vehicle is to the next lower weight class, the vehicle price class and the number of vehicles expected to be built. Further, it is possible to achieve weight reduction and cost reduction at the same time, as shown by the steel industry's ULSAB and LTS programs.
- There is no indication that OEMs are willing to pay anything for weight savings because the end user is not either.
- These numbers reflect North American priorities/value perceptions. Right now, reduced weight does not warrant increased price. Less price drives everything!
- This assumes that the pound(s) of weight reduction is necessary to reduce the weight class of the vehicle.
- This assumes that the CAFE standard requires weight reduction and fuel prices do not increase beyond the general rate of inflation.
- This question is nearly impossible to answer since it is highly model-specific. Additionally, mass reduction is not something the customer is willing to pay for.
- Ultimately, the technology will initially drive the price up for increased fuel efficiency, but since the end item consumer expects it for nothing, OEMs will drive cost out elsewhere so the net increase to the platform is $0.
- You can calculate this directly from the CAFE fine value. The customers are not pushing hard for improved F/E, so the industry will only pay for mass savings at a rate of the cost of the fines. A TWC (125 lbs.) is worth about .3 mpg, and the fine is $5.00 per .1 mpg, so mass savings are only worth about $15.00/125 lbs. at the macro level. If, on the other hand, you have a vehicle very close to a TWC break point, you might pay $5.00 or $10.00/lb. to make the drop into the next lower TWC.

Discussion

Panelists estimate that vehicle manufacturers will currently pay $1.00 to reduce the weight of a vehicle one pound. This is forecast to increase to $4.00 by 2007 at a CAFE of 35 mpg.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was first asked in the 1994 survey Delphi VII. Results for the current survey are compared to those for the previous two surveys in the following table.

Value of a Pound of Weight Savings (1997 Dollars)						
	1994 Delphi VII		1996 Delphi VIII		1998 Delphi IX	
Fuel Economy	For Year	$/lb.	For Year	$/lb.	For Year	$/lb.
Current 27.5 mpg	1993	2.18	1995	1.06	1997	1.00
Future 27.5 mpg	1998	2.18	2000	1.06	2002	1.25
30 mpg	2003	3.28	2005	2.12	2007	2.50
35 mpg	2003	4.37	2005	3.09	2007	4.00

Results for the three surveys are similar, with the exception of the results for 1994 Delphi VII survey for 1993 and 1998 at 27.5 mpg, which are about two times higher than the later two surveys.

Strategic considerations

This question is similar to TECH-8. The strategic considerations noted in that question apply here also. In that question, panelists forecast that manufacturers would spend $125 in 2007 at a CAFE of 35 mpg to improve one mpg. A general rule of thumb is that decreasing vehicle weight by a test weight class of 125 lb will improve fuel economy by 0.5 mpg. On that basis, one mile per gallon would equate to 250 lb. Per the current question, panelists forecast that manufacturers would spend $4.00 per pound, or $1000 for one mpg. This large discrepancy may indicate that there is not a rigorous process within the manufacturers for making these assessments. Manufacturers may want to institute such an analysis process to provide guidelines for suppliers.

It should be noted that weight reduction may have a compounding effect. For example, if engine weight is reduced by the use of aluminum in place of cast iron, vehicle suspension springs, tires, brakes and engine cradle may also be reduced in weight since they no longer must support the heavier engine.

The comments section of this question are important to read. They collectively present a comprehensive discussion of the topic and amplify the complexity of the issue.

TECH-42. How likely are federal or state government legislation and regulations to require the recyclability of automotive materials in 2002 and 2007?

Scale: 1 = extremely likely 3 = somewhat likely 5 = not at all likely

Regulatory Issues	Mean Response 2002	Mean Response 2007
Specific regulation for the following:		
Disposal of automotive fluids	2.3	1.7
Disposal of used tires	2.4	1.8
Establishment of uniform identification/coding standards for materials to facilitate separation	2.6	1.9
Specific regulation for the following		
Recyclability of plastics/polymers	2.7	2.0
Ban on some current automotive materials	2.9	2.2
Minimum recycled content	3.1	2.6
Financial penalties/incentives based on recycled content	3.5	2.5
"Take-back" regulations making manufacturers responsible for final product disposition	3.7	2.8

Selected edited comments

- Some materials are already being phased out, i.e., a/c refrigerant, however government has been unable to adequately control replacement materials to ensure some net benefit.
- The social need is here now. Only the slow speed with which governments act is preventing these from all becoming law tomorrow. Thus, we can expect them all to be law by 2007. The only action that will prevent the need for laws is for all the OEMs to implement these as good corporate citizens.

Discussion

Panelists forecast that federal or state governments are somewhat likely to require recyclability in several areas related to automotive materials by 2007. Legislation and regulations in the areas of uniform identification/coding standards, disposal of automotive fluids and used tires, and recyclability of plastics/polymers are forecast to be highly probable.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Comparison of forecast: MAT-10

There is a statistically significant difference in mean responses between technology and materials panelists for the issues and years shown in the following table.

Regulatory Issues - 2002		
	Technology	Materials
Ban on some current automotive materials	2.9	3.5
Establishment of uniform identification/coding standards for materials to facilitate separation	2.6	3.1
Financial penalties/incentives based on recycled content	3.5	3.8
Specific regulations for:		
Disposal of used tires	2.4	2.8
Recyclability of plastics/polymers	2.7	3.2
Regulatory Issues - 2007		
"Take-back" regulations making manufacturers responsible for final product disposition	2.8	3.3

For all areas where there is a significant difference, technology panelists rate the likelihood of legislation and regulation higher than materials panelists. It should be noted that the largest difference in mean values is only 0.6 rating points.

Trend from previous Delphi surveys

The results of the current and past three surveys are presented in the following table. Results for all surveys are for ten years from the time of the survey.

Regulatory Issues	Mean Forecast 1-5*			
	1992 Delphi VI	1994 Delphi VII	1996 Delphi VIII	1998 Delphi IX
Ban on some current automotive materials			2.3	2.2
Establishment of uniform identification/coding standards for materials to facilitate separation	2.3	1.9	1.8	1.9
Financial penalties/incentives based on recycled content	3.4	3.0	2.8	2.6
Minimum recycled content			2.6	2.5
Disposal of automotive fluids	1.7	1.9	1.7	1.7
Disposal of used tires	2.2	2.0	1.7	1.8
Recyclability of plastics/polymers	2.5	2.3	2.1	2.0
"Take-back" regulations making manufacturers responsible for final production disposition	3.5	3.2	3.1	2.8

*Scale: 1= extremely probable/likely, 5= not at all probable/likely

There is generally good agreement between the current and past surveys. This current survey indicates a higher probability of legislation as compared to each preceding survey.

Strategic considerations

Most of the vehicle today is recycled and the industry is generally being proactive. There are areas such as plastics, tires, automotive fluids and parts coding, however, that are more difficult to address. Manufacturers are working on these areas. A proactive approach by manufacturers may circumvent future legislation or, at least, give the industry a strong voice in formulating policy and regulations.

It is likely that recycling cost will have to be considered in the future in determining total life cycle material cost. It is also likely that new technology, e.g., methods to use recycled plastic, will be developed and will alter our views on the recyclability of automotive materials.

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TECH-43. What percentage of North American-produced passenger cars will use an integral frame or other designs in 2002 and 2007?

		Median Response		Interquartile Range	
Frame Construction	**1996***	**2002**	**2007**	**2002**	**2007**
Passenger Cars					
Integral body/frame or unibody	90.6%	92%	92%	90/93%	87/95%
Separate body/frame	5.3	3	2	3/5	1/4
Space frame	4.1	5	5	4/6	3/10
Total	100%				
Sport Utility Vehicle					
Integral body/frame or unibody	15.6%	20%	25%	17/22%	20/35%
Separate body/frame	84.4	80	70	75/81	60/79
Space frame	0	0	2	0/2	0/6
Total	100%				
Pickup					
Integral body/frame or unibody	0%	0%	2%	0/5%	0/10%
Separate body/frame	100	100	95	95/100	90/100
Space frame	0	0	0	0/0	0/0
Total	100%				

***Source:** Ward's Automotive Reports, Jan. 20 and Feb. 3, 1997 and OSAT estimates.

Selected edited comments

- Space frames keep showing up in technical forums/auto shows. The "spark" is more likely to ignite rather than die out.

Discussion

Panelists forecast that the type of frame used in passenger cars and pickup trucks will be little changed in the next decade. However, the use of the integral body/frame design is forecast to increase to 25 percent in sport utility vehicles.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of those shown in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

Passenger Car Frame Construction				
	2002 Mean		2007 Mean	
	Mfr.	Supp.	Mfr.	Supp.
Separate body/frame	3.2%	4.1%	1.9%	3.7%

Manufacturers forecast a somewhat lower penetration of separate body/frame in 2002 and 2007

than did suppliers.

Comparison of forecast: MAT-35

There is a statistically significant difference in mean responses between technology and materials panelists for pickup trucks in the years shown in the following table.

Pickup Frame Construction - Percent				
	2002		2007	
	TECH	MAT	TECH	MAT
Integral body/frame or unibody	3.2	.4	7.1	2.9
Separate body/frame	96.3	99.1	-	-

Technology panelists forecast a higher use of integral body/frame for pickup trucks than did materials panelists.

Trend from previous Delphi surveys

There is good agreement between the current and past surveys.

Strategic considerations

Integral body/frame is the predominant design for passenger cars. Considerable weight savings have been realized compared to separate body/frame designs. The trend towards increased use of integral body/frame is forecast for sport utility vehicles and minivans in the next decade. Many owners use these vehicles in a similar manner to passenger cars and do not require heavy trailer towing or load carrying requirements. It is reasonable to assume that these vehicles will become more like passenger cars in the future. Therefore, in addition to lighter vehicle designs, these vehicles will require improved ride and handling.

The space-frame design has been used successfully on the Saturn vehicle line for several years. In spite of this successful experience, panelists do not forecast a significant move in that direction for passenger cars.

Separate body/frame designs are forecast in almost all pickup trucks. These vehicles are designed for heavy load-carrying capacity. Still, the small increase in body/frame construction for 2007 may be significant. This may indicate the emergence of a new class of pickup or design methodology. Anytime an unexpected forecast occurs with a Delphi panel, it is important to watch trends closely.

TECH-44. What percentage of North American-produced passenger cars incorporate the following suspension features currently and will in 2002 and 2007?

	Median Response			Interquartile Range		
Suspension Features	**Current**	**2002**	**2007**	**Current**	**2002**	**2007**
Front Suspension Configuration						
MacPherson struts	80%	80%	73%	65/80%	70/86%	67/86%
Twin A-arm	20	20	25	20/30	13/30	13/32
Rear Suspension Configuration						
Independent	64%	70%	75%	60/66%	69/74%	70/80%
Non-independent	36	30	25	35/40	25/30	20/30
Springs						
Air	3%	5%	5%	1/5%	2/10%	2/10%
Oil/fluid	1	2	2	0/7	0/10	1/10
Composites	2	4	6	1/3	2/10	2/16
Steel	92	90	84	80/97	70/95	57/95
Self leveling	6%	10%	10%	2/10%	2/15%	5/20%
Ride/Handling						
Passive control (present system)	n/a*	90%	83%	n/a*	80/95%	68/90%
Passive-driver selected	n/a*	5	5	n/a*	2/6	2/10
Semi-active (damping controls)	n/a*	5	8	n/a*	2/10	4/10
Active (springs & damping controls)	n/a*	1	2	n/a*	0/2	1/5

* These items appeared as part of TECH-45 in the Round 1 questionnaire; therefore, current estimates are not available.

Selected edited comments

- Cost vs. benefit considerations combined with increasing cost pressures will significantly constrain smart suspension rollout.
- Drive-by-wire may appear in ten years along with active suspension.
- I believe active suspensions will play a larger role in vehicles for the near- and long-term future. Self-leveling will become more of a standard feature on sport utility and luxury models. With active suspensions, independent rear-suspension configurations will grow.
- I believe that we will see a lot more independent rear suspensions in the near future.
- I disagree that active suspension will play a larger role. The cost-to-benefit ratio does not exist. Technology is also not reliable and very difficult to maintain.
- I do not feel active suspension percentages in the market will increase significantly due to cost. Sport utilities will utilize more independent suspension axles in the front and rear positions. Half-ton pickups will also use more independent front suspensions and begin to use independent rear suspensions for better ride. Three-quarter and 1 ton trucks will continue to be the workhorse and use beam front and rear axles.
- Performance demands will continue their implementation into lower level models.
- Rear suspensions will trend toward more independents, more ride travel, and less mass.

- Recent European advances suggest that independent rear suspension will become a customer expectation.
- The customer wants a "good ride" and does not care about suspension design. The drive for a light weight, lower cost and more efficient package will drive design back toward nonindependent suspensions which can give the same ride if done correctly.
- There will be a move to electronic control. Full active suspension will be too heavy to be incorporated, especially for the marginal gain over semiactive and adjustable-passive suspensions.
- With the demise of the big RWD passenger vehicles, nonindependent suspensions will become nearly extinct.

Discussion

Panelists forecast the following trends in the next decade regarding suspension features:

Front suspensions: MacPherson struts will continue to be the predominant configuration, with a slight increase in the use of twin A-arms.

Rear suspensions: The use of independent rear suspensions is forecast to increase to 75 percent in 2007 from 64 percent currently.

Ride/handling: Driver-selected, semiactive and active controls will be used on 8 percent of vehicles or less by 2007.

Self-leveling: Penetration is forecast to increase to 10 percent by 2007 from 6 percent currently.

Springs: Steel springs will continue to be used on most vehicles, but the use of composites and air springs will increase.

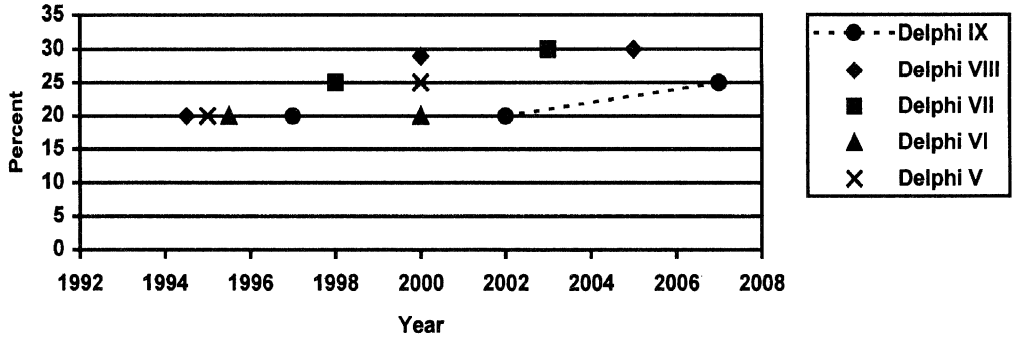
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

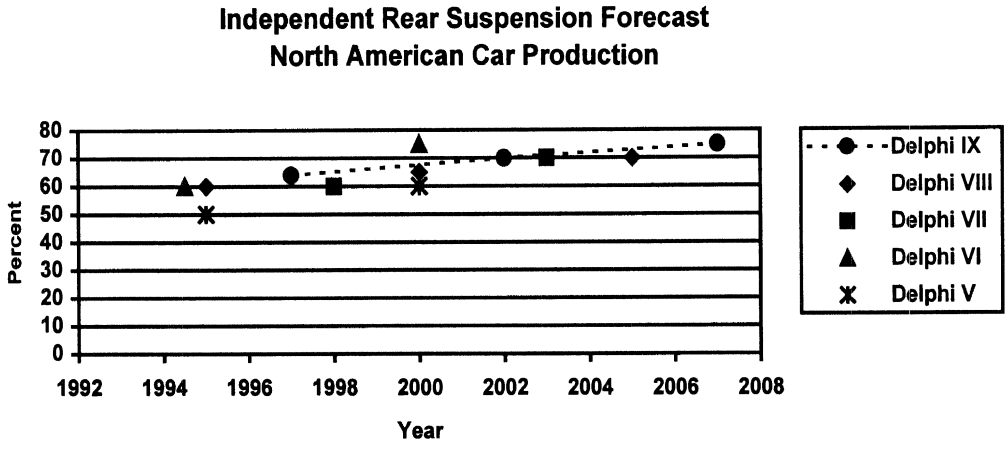
Trend from previous Delphi surveys

Results from the current survey are compared to those of past surveys in the following graphs:

Front Suspension - Percent Twin A-arm



The current forecast for twin A-arm suspensions is lower than in previous forecasts.



The current forecast for independent rear suspensions is in agreement with previous forecasts. The current forecast is in general agreement with past forecasts with regards to springs, self leveling and ride and handling systems.

Strategic considerations

Cost constraints may continue to limit the application of high-performance suspension systems. Many of these features are transparent to the majority of consumers and may not merit application, particularly in lower-priced family vehicles.

Composite springs are attractive for their weight-savings potential but, again, must pass the test of cost.

There are some very innovative suspension designs in the market today. Still, there is continuing room for creativity regarding suspension design, materials, and the integration of electronics in the system. Cost will continue as an important factor in many vehicle classes.

TECH-45. What percentage of North American-produced passenger cars will have the following steering features in 2002 and 2007?

		Median Response		Interquartile Range	
Steering Features	**1996***	**2002**	**2007**	**2002**	**2007**
Power Steering					
Power					
Electrical with electronic control	0%	2%	10%	1/5%	3/15%
Hydraulic with electronic control	4.2	8	15	5/10	8/20
Traditional hydraulic	94.1	89	76	85/92	66/85
Nonpower	1.7	1	0	0/1	0/1
Total	100%				
Speed-sensitive power steering	n/a	10%	20%	5/23%	10/40%

***Source:** Ward's Automotive Reports, Feb. 17, 1997 and OSAT estimates.

Selected edited comments

- CAFE standards will play the largest role in defining the usage of electrical control of power steering (EHPS & EPS). If held firm to current standards, I predict major growth in these areas. Smaller European vehicles have tremendous growth in this area, primarily driven by fuel prices.

Discussion

Panelists forecast that power steering will be used on all passenger cars by 2007. Use of electric power steering with electronic control and hydraulic power steering with electronic control are forecast to increase in use to 10 percent and 15 percent respectively in the same time frame.

Speed-sensitive power steering use is forecast to increase to 20 percent by 2007.

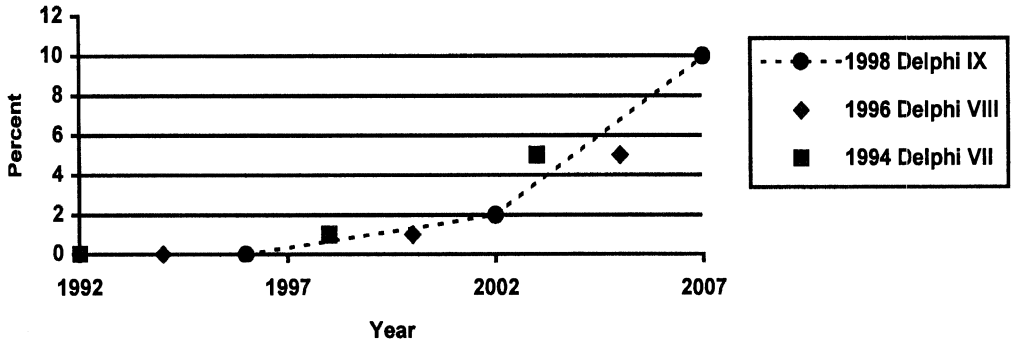
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

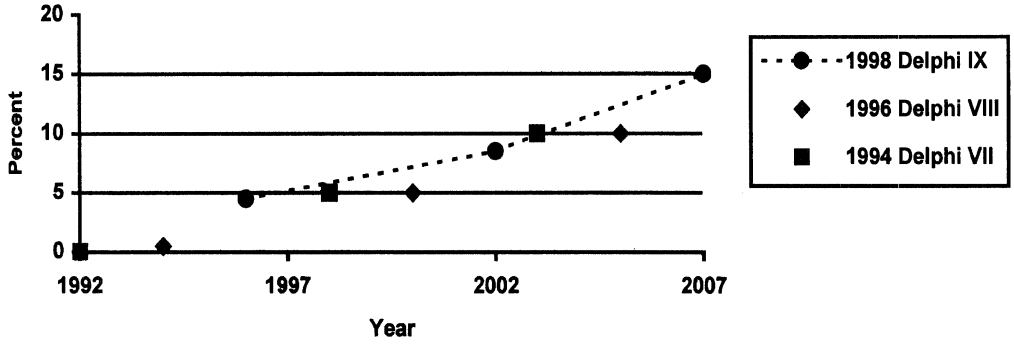
This question was asked in a different format prior to the 1994 Delphi VII survey. Comparisons of the current and two previous surveys are as follows:

Electric/electronic Power Steering



The current forecast is in agreement with previous forecasts for electric/electronic power steering.

Hydraulic with Electronic Control Power Steering



The current forecast is in agreement with previous forecasts for hydraulic with electronic control power steering.

Nonpower Steering:

The current forecast is in agreement with previous forecasts for nonpower steering.

Strategic considerations

Electric power steering will likely be used in future electric vehicles. The forecast penetration for electric power steering is considerably greater than the forecast for electric vehicles. Panelists, therefore, forecast modest use in conventionally powered vehicles. The advantage for this feature is low power consumption, which is a benefit for fuel economy. There may be other driving-feel benefits as well.

Hydraulic power steering with electronic control can be used to modify steering effort based on vehicle speed or driver preference.

It should be noted that there are significant efforts underway to develop both types of new power steering. Results are promising and, based on recent progress, the forecast may be low. If a supplier is potentially impacted by new power steering technology, it is imperative to track trends closely.

TECH-46. Please forecast, in percent, the total domestic and import U.S. market for the following technologies in 2002 and 2007

		Median Response		Interquartile Range	
Technology	**1995***	**2002**	**2007**	**2002**	**2007**
Passenger Car					
Antilock brake system	55.9%	70%	80%	60/75%	70/90%
Four-wheel disc brakes	7.0	10	15	10/15	12/25
Traction (antispin) control	10.8	15	20	15/20	20/40
Yaw or stability control	0	2	7	1/5	4/10
Light Truck					
Two-wheel antilock brakes	36.9%	30%	20%	25/35%	10/25%
Four-wheel antilock brakes	55.4	70	80	60/75	75/85

*Source: Ward's Automotive Yearbook, 1996. Automotive News Market Data, Aug. 1996, and OSAT estimates.

Selected edited comments

- Due to consumer awareness, the use of antilock braking systems will remain "as is" or decrease. Additional attempts will be made to develop brake-by-wire systems to make antilock an obsolete design. Four-wheel disc brakes will be reduced for costs reasons.
- Four-wheel antilock systems will be integrated into traction-control systems as awareness of truck concerns resurface.
- Lower cost ABS and traction control will drive installation rates. Introduction on high-volume vehicles in 97/98.
- Other traction-enhancement devices will be available in passenger cars for both traction and handling.
- Since customer awareness has shed a negative light on ABS and CAFE is an issue of concern with the large SUVs, there is a concentrated effort on brake-by-wire systems. Antilock brakes will remain at the current level as needed, and new technologies will absorb any increase in the usage of this type of product.
- Traction and yaw control require little extra hardware and will therefore be quickly piggybacked into ABS controls and systems.

Discussion

Panelists forecast that antilock brakes will be installed on 80 percent of passenger cars by 2007. Traction control is forecast for 20 percent of passenger cars in the same time frame. Four-wheel antilock brakes are forecast for 80 percent of light trucks by 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers, with the exception of traction control on passenger cars for 2007. In this case, the mean forecast for manufacturers is 38 percent, whereas it is 25 percent for suppliers.

Comparison of forecast: MKT-42

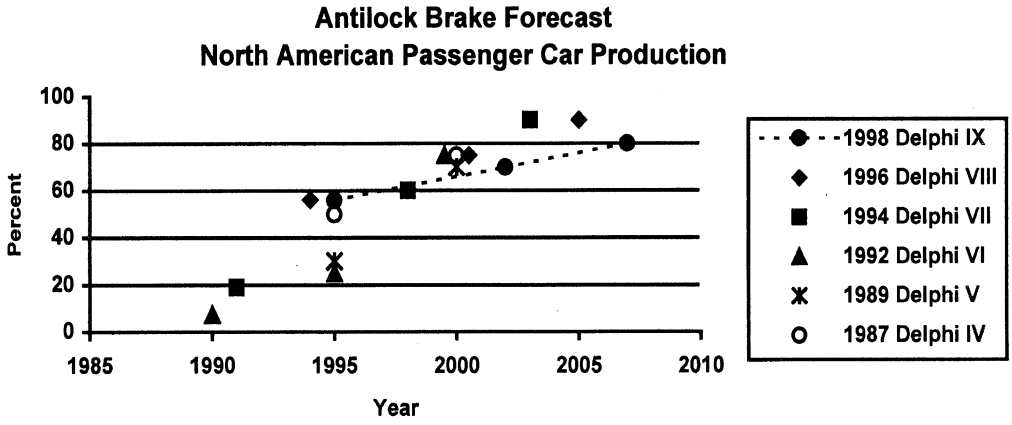
There is a statistically significant difference in mean responses between technology and marketing panelists for the brake technologies in passenger cars and light trucks in the years shown in the following table.

Brake Control Technology - Percent				
	2002		2007	
	TECH	MKT	TECH	MKT
Passenger Car				
Antilock brake system	-	-	81	76
Four-wheel disc brakes	-	-	23	16
Light Truck				
Four-wheel antilock brakes	68	64	78	70

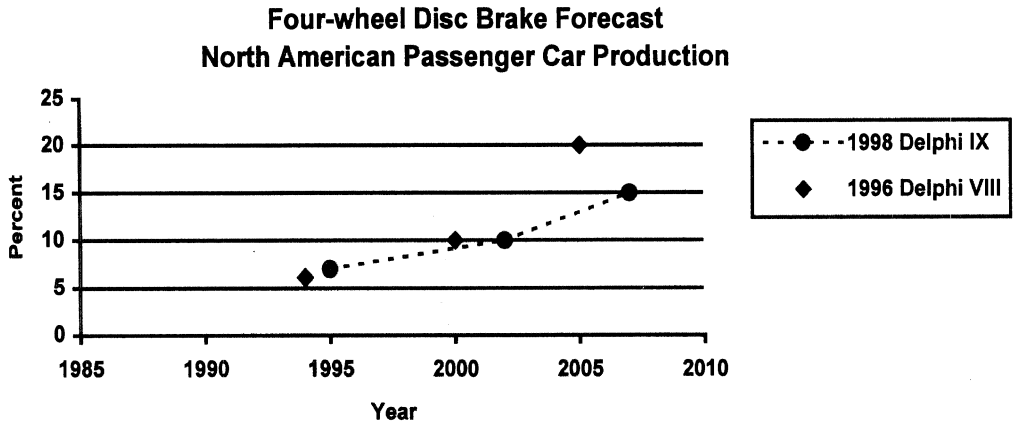
Technology panelists forecast higher use of antilock brakes and four-wheel disc brakes in 2007 than did marketing panelists. Technology panelists also forecast higher use of four-wheel antilock brakes on light trucks in 2002 and 2007 than did marketing panelists.

Trend from previous Delphi surveys

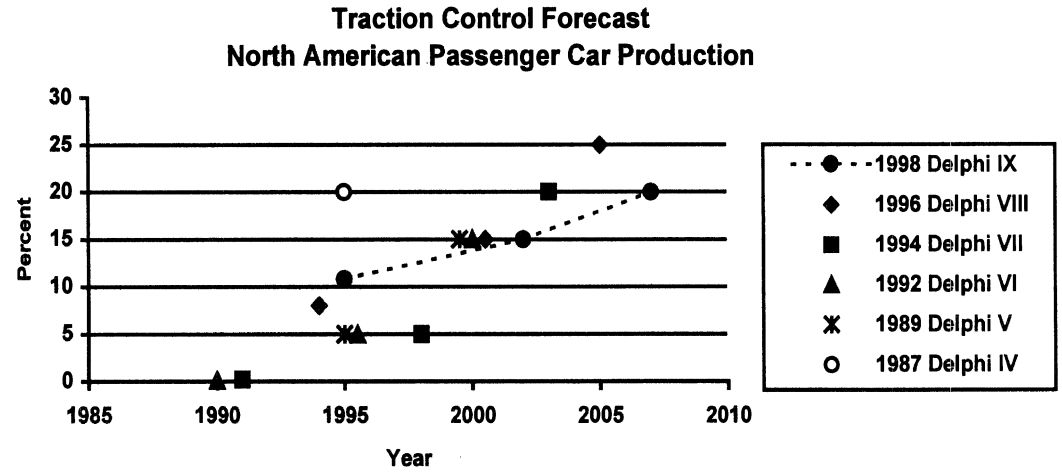
Results for the current and previous surveys are shown in the following graphs. Yaw control was not covered in a previous forecast.



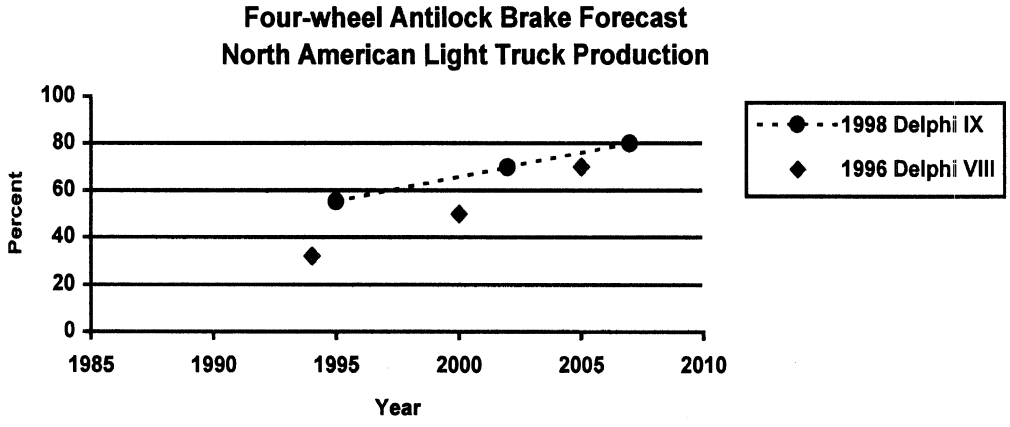
Results for the current survey are in general agreement with past surveys for antilock brakes.



The current forecast for 2007 is somewhat lower than the previous forecast for 2005 for four-wheel disc brakes.



The results of the current forecast for traction control are in general agreement with past forecasts.



The forecasts of the current survey are similar to those of the previous survey (Delphi VIII), although the actual baseline for 1995 has increased significantly in the current survey.

Strategic considerations

Panelists forecast increased use of antilock brake systems on both passenger cars and light trucks. Although safety data have failed to prove the benefit of this feature, those living in northern climates can attest to the superior braking and steering control available on ice and snow. Increased braking distances on dry surfaces may negatively impact safety, but the need for driver education on the use of antilock brakes may be a larger factor. Cost for this feature has decreased significantly in recent years, which likely explains the forecast for increased application.

Traction control is forecast to increase to 20 percent of passenger cars by 2007. This feature provides improved acceleration on ice and snow at a fraction of the cost of all-wheel drive. Performance on ice and snow is inferior to all-wheel drive in these conditions, however. Traction control provides the most benefit to rear-wheel drive vehicles, which have declined in numbers dramatically in recent years.

Yaw control is a feature that is currently available only on sport and luxury vehicles because of the high cost. Also, it is a benefit primarily in aggressive driving situations, seldom encountered by most drivers.

It is important to note that technology is not standing still in this area. As noted in several comments, electric brake systems could alter the approach to ABS and traction control. Also, as noted in the comments, we are improving our ability to integrate features using the same basic set of components, thus reducing cost.

TECH-47. What percentage of North American-produced passenger cars will incorporate the following tire features in 2002 and 2007?

	Median Response		Interquartile Range	
Tire Features	**2002**	**2007**	**2002**	**2007**
Airless spare	3%	5%	0/10%	2/20%
Failure-sensing devices	5	10	2/10	5/20
Puncture resistant/self-sealing	10	20	2/25	5/36
Run-flat	6	10	2/18	5/30
No spare tire for vehicle	5	10	1/10	3/25

Other Responses:

Original owner tread warranty - 2002: 2; 2007: 4

Selected edited comments

- Consumers still like the security of a full-size spare.
- I don't think Americans will give up their spares.
- It depends on cost.
- Must have failure-sensing or run flat.
- Public perception will never eliminate the spare tire.
- Run-flat needs a breakthrough to gain substantial volume (ride quality, rolling resistance, aspect ratio)...will take off when/if breakthrough comes?
- Trend is towards run-flat with no spare tire.

Discussion

Panelists forecast that several evolving tire features will see meaningful application rates in the next decade. No spare tire is forecast for 10 percent of passenger cars in 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

Results of the previous four forecasts are compared to the current survey in the following table.

For year →	1995		1998	2000			2002	2003	2005	2007
	Delphi V	Delphi VI	Delphi VII	Delphi V	Delphi VI	Delphi VIII	Delphi IX	Delphi VII	Delphi VIII	Delphi IX
Forecast year →	1989	1992	1994	1989	1992	1996	1998	1994	1996	1998
Airless spare			0%			5%	3%	1%	7%	5%
Failure-sensing	2	1	2	8	5	5	5	10	10	10
Puncture resistant		5	5		10	10	10	15	15	20
Self sealing										
Run-flat	5	1	2	10	5	5	6	10	10	10
No spare tire	5	0	0	10	3	2	5	2	8	10

The forecast use rate of the above tire features in the current survey are in general agreement to those forecast in previous surveys.

Strategic considerations

The spare tire has been deleted on the 1998 Corvette. Elimination of the spare tire reduces vehicle weight and cost and increases usable space. In order for manufacturers to eliminate the spare tire on high volume vehicles, however, technology must be demonstrated to the satisfaction of vehicle owners that either the tires on the vehicle cannot go flat, or they can be driven long distances at reasonable speeds if they do go flat. Puncture-resistant/self-sealing and run-flat are technologies that have these objectives in mind. Considerable experience with these technologies in conjunction with a spare tire will be required before the spare tire can be removed. Goodyear Tire and Rubber Company plans to convert all of its replacement tire capacity to run-flat beginning in 1998. Perhaps this is the beginning of the end of spare tires.

Increasing pressure to meet forecast CAFE increases will increase interest in removing the spare tire. Based on their comments, some panelists do not believe that this will happen.

There are some very innovative and relatively inexpensive tire pressure-sensing technologies emerging. This is a necessary feature with run-flat designs.

TECH-48. What percentage of North American-produced passenger cars and light trucks will incorporate rear seat, side and knee bolster airbags in 2002 and 2007?

		Median Response		Interquartile Range	
Airbag Applications	**1996***	**2002**	**2007**	**2002**	**2007**
Passenger Cars					
Rear seat occupants	0%	2%	5%	0/5%	1/10%
Side airbags	<1	5	15	3/15	10/30
Knee bolster	0	1	5	0/5	0/10
Light trucks					
Passenger side	37.1%	55%	85%	50/80%	61/100%
Rear seat occupants	0	0	0	0/2	0/5
Side Airbags	0	5	18	3/20	10/40
Knee bolster	0	0	1	0/5	0/5

* **Source:** Ward's Automotive Reports, Mar. 3, 1997 and OSAT estimates.

Selected edited comments

- Airbags will grow slightly in use, but intelligence will be built in.
- Applications of side airbags for vans and SUVs will emerge from government pressure, not from customer demand.
- Applications of side airbags in light trucks will largely be in minivans and SUVs, but I believe that there is a market in those segments.
- As smart airbags are developed, current concerns will be greatly reduced or eliminated.
- Assumes minimal or no changes to FMVSS requirements.
- I see airbags as being a safety area that consumers may not believe to be cost beneficial.
- Passenger-side inflated-restraint (PSIR) issues with children will take the air out of rear seat frontal airbags. Side airbags will catch on as a good thing.
- Recent PSIR/inflation-induced injury concerns would seem to doom rear-seat airbag considerations.
- Safety will drive consumer purchasing decisions, particularly in minivans and upscale SUVs.
- Side airbags have the least benefit in light trucks.
- Side airbags in light trucks will allow thinner doors.
- Some type of active side-safety system will reach the truck market prior to the 2000 model year.
- The airbag scare will soon be over; side airbags will cautiously move forward.
- The use of side airbags in light trucks depends largely upon the government mandates for trucks to meet car standards.
- Until "smart" airbags are introduced, the public will be cool to these devices.

Discussion

Panelists forecast some use of rear seat, side, and knee bolster airbags in passenger cars by 2007. An 18 percent penetration of side airbags in light trucks is forecast for 2007. No use of rear seat and knee bolster airbags is forecast for light trucks in this time frame, however. Passenger-side airbags for light trucks are forecast to increase from 37 percent currently to 85 percent in 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

Knee bolster airbags were not included in a previous Delphi survey. Trucks were not covered in Delphi V and Delphi VI. Results for other features are compared in the following table.

Forecast Years →	1994*	1996*	1998	2000			2002	2003	2005	2007
	1996	1998	1994	1989	1992	1996	1998	1994	1996	1998
Airbag Applications	Delphi VIII	Delphi IX	Delphi VII	Delphi V	Delphi VI	Delphi VIII	Delphi IX	Delphi VII	Delphi VIII	Delphi IX
Passenger Cars										
Rear seat occupants	0%	0%	2%	2%	3%	2%	2%	10%	6%	5%
Side	0	0	1		10	5	5	5	20	15
Light trucks										
Passenger side	9.1	37%	20			50	55	50	90	85
Rear seat occupants	0	0	0			0	0	0	3	0
Side	0	0	0			2	5	0	10	18

*Actual data

There is general agreement between the current and past surveys except that the forecast for side airbags in light trucks is higher in the current forecast than in previous forecasts.

Strategic considerations

There has been considerable controversy surrounding airbags in the recent past. Children in infant seats in the front seat and small adults that may be in near proximity to the dash panel can be injured or killed by deploying airbags. On the other hand, many people may be alive today because of airbags. Data indicate that many more people are saved than killed by airbags.

Airbags are of significant benefit to unbelted vehicle occupants. In low-speed accidents, however, a belted occupant is more likely to be injured in a vehicle with an airbag than in one without an airbag. This is a result of abrasions and lacerations caused by the deploying airbag. At high speeds, even a belted occupant may benefit from an airbag in the event of a collision.

It is likely that the above concerns explain the somewhat lower forecast in the current survey for rear seat and side airbags in passenger cars and passenger-side airbags in light trucks as compared to Delphi VIII forecasts.

Recycling of vehicles with airbags will become an increasing problem, as airbag actuators must be deactivated prior to recycling.

In spite of the current controversy surrounding airbags, panelists forecast that overall use of

airbags will continue to increase.

Clearly, the properly fastened seat belt and shoulder harness is very effective, and the primary restraint system. The airbag is of secondary value.

TECH-49. What percentage of North American-produced passenger cars and light trucks will incorporate the following airbag features in 2002 and 2007?

	Median Response				Interquartile Range			
	Passenger Cars		Light Trucks		Passenger Cars		Light Trucks	
Feature	2002	2007	2002	2007	2002	2007	2002	2007
Manual switch to deactivate passenger-side airbag	10%	5%	20%	10%	4/20%	0/11%	9/31%	0/25%
Reduced-power airbags	50	75	50	75	48/80	30/100	30/80	30/100
"Smart" airbags	25	70	20	50	20/46	40/83	10/40	39/80

Other Responses:

Completely new "safe" passive restraint system – LT: 2007

Current system

Selected edited comments

- A smart airbag system is not yet fully defined.
- After a period of focus, the smart system will become prominent due to the liability of the other options.
- Corporate America would never produce the switch for deactivation of an airbag.
- Corporate lawyers will not allow deactivation switches.
- Corporate lawyers won't allow switches. The law should stop trying to protect people who won't wear seat belts.
- Corporate lawyers would not allow deactivation switches.
- I believe deactivation switches will be a very temporary solution to the problem, if they are used at all.
- I don't think smart airbags will be fully "baked" by 2002. Consequently, I would predict a significant number of manual deactivation switches to linger around.
- LCD = lowest common denominator (dumbing down will prevail!)
- Manual option is a nonstarter under current tort law provisions.
- Per current government/FMVSS 208 intent, depowered airbags must be repowered when smart airbags are executed in a given vehicle program.
- Switch should be discontinued by 2002; depowering will start then.
- The U.S. government plans to have a smart-airbag law in place for 2001 and beyond.
- This assumes a FMVSS rule change to allow manual deactivation devices on passenger cars and automatic deactivation devices for 2007. It also assumes that reduced-power airbags are those with less power than 1996-1997 model airbags, and will be allowed in 2002 and 2007.
- Trucks will be slower for incorporation of smart systems, especially since they vary in weight so much.

- With the implementation of "smart" airbags, there will be no need for depowering. It was merely a short-term solution before smart airbags were technically feasible AND reliable.

Discussion

Panelists forecast that there will be some application of a manual switch to deactivate passenger-side airbags in the next decade. They further forecast that most vehicles would have reduced-power airbags and "smart" airbags in the same time frame.

Manufacturer/supplier comparison

There is a statistical difference in responses between manufacturers and suppliers for reduced-power airbags as shown in the following table.

Reduced Power Airbags							
Passenger Car				Light Truck			
2002 Mean		2007 Mean		2002 Mean		2007 Mean	
Mfr.	Supp.	Mfr.	Supp.	Mfr.	Supp.	Mfr.	Supp.
72%	45%	74%	56%	24%	32%	73%	53%

Manufacturers forecast a significantly higher use of reduced power airbags in passenger cars than suppliers.

There is also a statistical difference in responses between manufacturers and suppliers for a manual switch to deactivate passenger-side airbag for light trucks by 2002. In this case, manufacturers forecast a mean value of 37 percent compared to 18 percent for suppliers.

Trend from previous Delphi surveys

This question was not covered in a previous Delphi survey.

Strategic considerations

Panelists forecast that a manual switch to deactivate passenger-side airbags will see limited application in the next decade. For light trucks, these switches are forecast to see near-term application that will diminish as other solutions for airbag safety concerns are found.

Reduced-power airbags are forecast for most passenger cars and light trucks by 2007. The reduction in power can reduce low-speed injury and improve safety for children and small adults.

"Smart" airbags are forecast for more than half of all vehicles by 2007. These devices may sense the presence or absence of an occupant on the seat as well as determine the size of the occupant. Vehicle speed might also be used as a parameter in airbag deployment. Airbag deployment can be tailored accordingly, including deployment or nondeployment in addition to the deployment power.

It should be noted that data for this question was collected before the recent government/industry actions pertaining to airbags. Deactivation is now permitted; we are already seeing some depowered airbags in 1998 vehicles.

TECH-50. What percentage of passenger cars produced in North America will have the following vehicle systems by 2007?

	Median Response	Interquartile Range
Vehicle Systems	**2007**	**2007**
Adaptive cruise control	10%	5/30%
Collision warning systems	10	5/20
Automatic toll collection	10	4/20
Navigation system	10	5/20
In-vehicle message system	18	9/30
GPS/cellular phone-based safety system (i.e., GM "on-star" system)	20	10/40

Other Responses:

Driver aids - 2007: 65% (includes obstacle avoidance, vision enhancement, lateral control, automated highway systems)

Lane change warning - 2007: 1%

Selected edited comments

- A majority of the above systems will be provided by the aftermarket.
- All these items are expected, to a large extent, to become standard items on all luxury cars and, if the costs come down as projected, can be standard equipment in family vehicles.
- Collision warning technology will still have too many false-positives.
- Navigation will lie in with GPS/cellular phone. The cost is still high for navigators without "real-time" traffic conditions.
- While new features will continue to emerge, cost/affordability pressures will slow the trend toward ever-increasing features content.

Discussion

Panelists forecast that several emerging vehicle systems will be installed in 10 to 20 percent of passenger cars by 2007. GPS/cellular phone-based safety systems are forecast for 20 percent of passenger cars.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of GPS/cellular phone-based safety systems for 2007. For this item, manufacturers have a mean response of 37 percent, whereas the suppliers mean response is 21 percent. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

Comparison of forecast: MKT-43

Responses from Marketing panelists are not statistically different from those of Technology panelists.

Trend from previous Delphi surveys

This question was asked for the first time in the present format in the 1994 Delphi VII survey. GPS/cellular phone-based safety systems were not covered in previous Delphi forecasts. Results of the current survey are compared to the previous two surveys in the following table.

Vehicle Systems	1994 Delphi VII for the year 2003	1996 Delphi VIII for the year 2005	1998 Delphi IX for the year 2007
Adaptive cruise control	5%	10%	10%
Collision warning systems	8	5	10
Automatic toll collection	5	6	10
Navigation	5	10	10
In-vehicle message system	10	10	18

Current forecast penetrations of the above systems are the same or higher than previous forecasts.

Strategic considerations

The vehicle systems addressed in this question will likely appear first in luxury vehicles. As use increases in luxury vehicles, system costs will decrease. At some point, some or all of the systems may gain wide acceptance in family passenger cars, as well.

One of the panelists commented that a majority of these systems will be provided by the aftermarket. It is a challenge to vehicle manufacturers to provide these systems at competitive costs.

Affordability is also an issue for widespread application of new technology. This issue currently impacts vehicle sales. In spite of the desire by customers to have new devices on their vehicles, the reality may be that large numbers of customers will not be able to afford them. However, we should not underestimate the potential for electronics suppliers to significantly reduce cost. Their track record is very good in this regard. The lower-cost technologies of consumer electronics are increasingly applicable to the automotive environment.

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TECH-51. What percentage of North American-produced passenger car and light truck engines will be equipped with the following number of cylinders in 2002 and 2007?

Passenger Cars		Median Response		Interquartile Range	
Number of Cylinders	1996*	2002	2007	2002	2007
3	0.4%	1%	1%	0/1%	0/5%
4	49.2	50	54	49/55	49/60
6	38.7	40	39	35/40	30/42
8	11.7	10	7	8/11	5/10
10/12	0.0	0	0	0/0	0/0
Total	100%				

Light Trucks		Median Response		Interquartile Range	
Number of Cylinders	1996	2002	2007	2002	2007
3	0%	0%	0%	0/0%	0/0%
4	12.9	15	18	13/15	13/24
6	54.1	55	56	54/60	52/60
8	32.7	30	25	25/32	20/31
10/12	0.3	0	0	0/1	0/1
Total	100%				

***Source:** Ward's Automotive Reports, Feb. 3 and Feb. 24, 1997

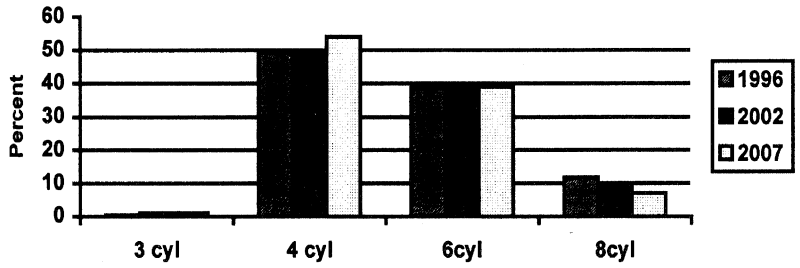
Selected edited comments

- Expect light-duty diesels (six-cylinder) to replace V8s in 2007.
- Fuel economy will play a major role in the decisions of size of engine—by EPA, fuel tax, cost of fuel.
- Some small engines will be used for hybrid powertrain.
- The increase in three-cylinder engines will be small diesel engines with hybrid propulsion systems. There will also be other engines such as stirling and fuel-cell engines.
- There will be no significant change in engine cylinder count.

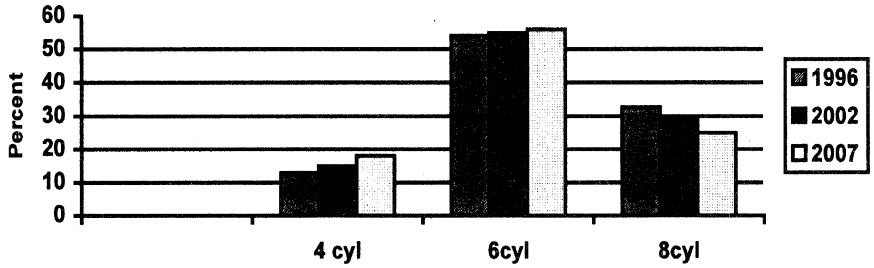
Discussion

Panelists forecast an increase in four-cylinder engines and a decrease in eight-cylinder engines in passenger cars and light trucks in the next decade. The volume of eight-cylinder engines in light trucks is forecast to remain significant by 2007 at 25 percent. The forecast distribution of number of cylinders in engines is shown in the following graphs:

Number of Cylinders - Passenger cars



Number of Cylinders - Light trucks



Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of passenger car eight-cylinder engines for 2007. For this item, manufacturers have a mean response of 6 percent, whereas suppliers mean response is 9 percent. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

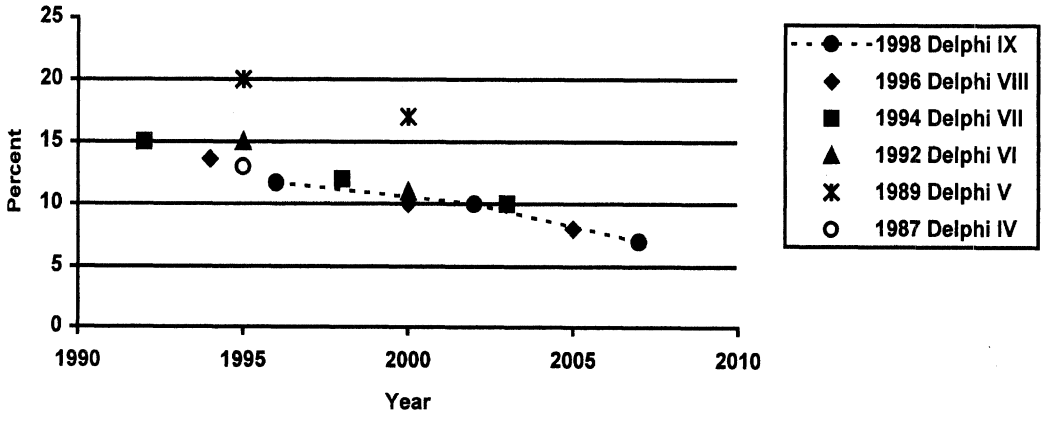
Trend from previous Delphi surveys

Results from the current survey are compared to those of the last four surveys in the following table and graphs.

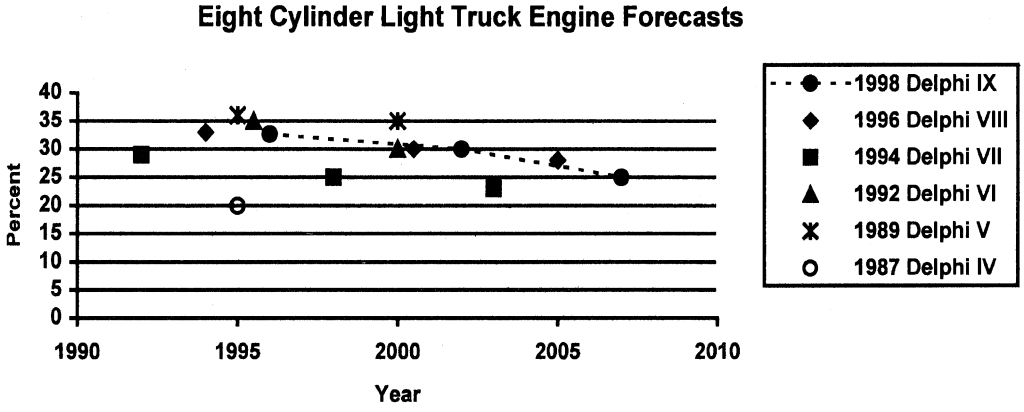
Passenger Cars										
For year →	1995		1998	2000			2002	2003	2005	2007
Date of Forecast →	1989	1992	1994	1989	1992	1996	1998	1994	1996	1998
Number of Cylinders	Delphi V	Delphi VI	Delphi VII	Delphi V	Delphi VI	Delphi VIII	Delphi IX	Delphi VII	Delphi VIII	Delphi IX
3	0%	0%	1%	1%	3%	2%	1%	2%	2%	1%
4	50	45	42	47	51	47	54	44	50	54
6	30	40	42	35	35	40	40	43	42	39
8	20	15	12	17	11	10	10	10	8	7
10	0	0	1	0	0	0	0	1	0	0

Light-duty Trucks										
For year →	1995		1998	2000			2002	2003	2005	2007
Date of Forecast →	1989	1992	1994	1989	1992	1996	1998	1994	1996	1998
Number of Cylinders	Delphi V	Delphi VI	Delphi VII	Delphi V	Delphi VI	Delphi VIII	Delphi IX	Delphi VII	Delphi VIII	Delphi IX
Light-duty Trucks										
4	14%	15%	13%	15%	20%	15%	15%	15%	16%	18%
6	50	50	60	50	50	55	55	60	55	56
8	36	35	25	35	30	30	30	23	28	25
10/12			0			0.1	0	0	0	0

Eight Cylinder Passenger Car Engine Forecasts



Results for the current survey generally agree with past surveys for eight-cylinder engines in passenger cars. The results from Delphi V deviate from other surveys. This is likely because baseline numbers were not provided in that survey.



Results for the current survey generally agree with past surveys for eight-cylinder engines in light trucks. It is interesting to note that although the forecast is for decreasing use of eight cylinder engines in light trucks, the actual penetration has increased in the last few years. This can be seen by comparing baseline numbers for the last three surveys.

Strategic considerations

Panelists forecast decreasing use of eight-cylinder engines in both passenger cars and light trucks. This is in agreement with the forecast for higher fuel-economy requirements in TECH-3. The number of eight-cylinder engines in passenger cars has decreased in the last few years. The number of eight-cylinder engines in light duty trucks has increased, however. This is likely a result of the shift by consumers from large passenger cars to sport utility vehicles. The total number of eight-cylinder engines in passenger cars and light trucks combined is little changed in the past few years. Relatively stable fuel prices and CAFE requirements have delayed the shift to smaller vehicles and engines.

The forecast for an increase in four-cylinder engines and a decrease in eight-cylinder engines may cause a decrease in parts sold by suppliers that are number-of-cylinder dependent. Examples are spark plugs, valves, pistons and piston rings. Any move to electric or hybrid engines could also affect engine component suppliers. However, his move is forecast to be small in the next decade.

It should also be noted that there is a trend to use standardized component sets (including engines) across the world. This deproliferation of engine designs could have an impact on suppliers by decreasing part numbers and increasing volume of the common parts.

TECH-52. What percentage of six-cylinder engines in North American-produced passenger cars and light trucks will be 60° V-6, 90° V-6, and in-line (IL-6)?

		Median Response		Interquartile Range	
Six-Cylinder Engines	**1996***	**2002**	**2007**	**2002**	**2007**
Passenger Cars					
60° V-6	69.2%	71%	75%	70/75%	70/80%
90° V-6	30.6	28	25	25/30	20/30
IL-6	0.0	0	0	0/3	0/4
Light Trucks					
60° V-6	25.5%	30%	35%	26/34%	26/40%
75° V-6	2.7	2	2	0/3	0/3
90° V-6	52.1	50	49	45/56	39/58
IL-6	19.7	15	15	15/20	10/24

*Source: Ward's Automotive Reports, Feb. 3 and Feb. 24, 1997; Gilbert Way, "U.S. Passenger Car and Light Duty Truck Models – Engine Specifications and Emission Systems," August, 1995; and OSAT estimates.

Selected edited comments

- A flat four-cylinder end to end (8 piston) two-stroke engine will enter the market as fuel economy enters the picture.
- As seen by the current plant capacity and general trends in vehicle sales, the V-6 - 60° aluminum engines will increase substantially.
- Hood lines, crush space, overhangs, turning circles and balance characteristic trade-offs inherent with the different engine configurations will continue to provide engineers with much opportunity for "lively debate." I would expect the 60° to slowly prevail over the 90° V-6 configuration in transverse front-wheel drive (TFWD) vehicle applications.

Discussion

Panelists forecast that a 60° design configuration will be used increasingly in six-cylinder engines in the next decade. No application of in-line six-cylinder engines is forecast for passenger cars, and the use in light trucks is forecast to decrease from 19.7 percent in 1996 to 15 percent in 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

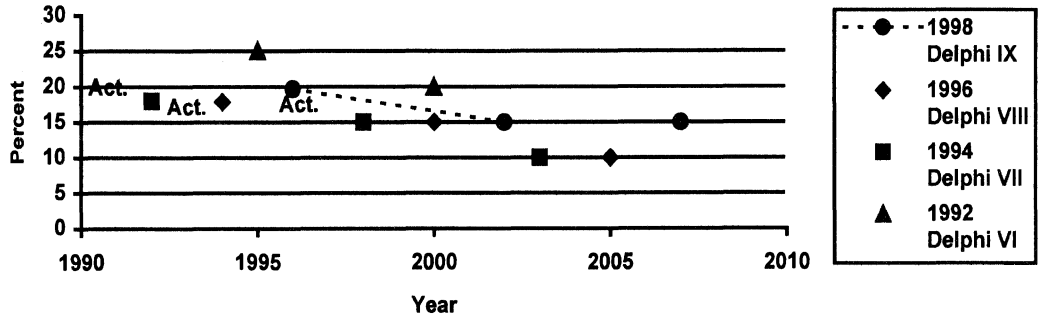
Trend from previous Delphi surveys

This question was asked in the current format for the first time in the 1996 Delphi VIII survey. Previous surveys asked only whether the six-cylinder engines would be in-line or V-6.

The 1992 Delphi VI survey forecasted a 10 percent penetration of IL-6 engines in passenger cars for 1995 and 2000. The 1994 and 1996 surveys forecasted no use of IL-6 engines in passenger cars, which is in agreement with the current survey.

The forecasts for use of IL-6 cylinder engines in light trucks is summarized in the following graph.

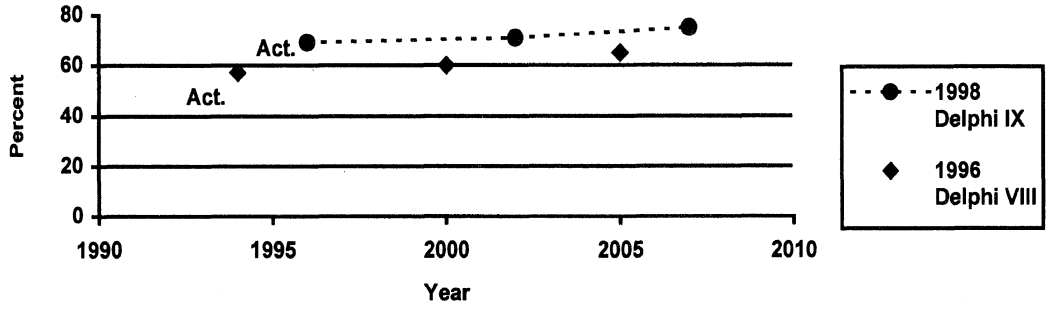
IL-6 Light Truck Engine Forecasts



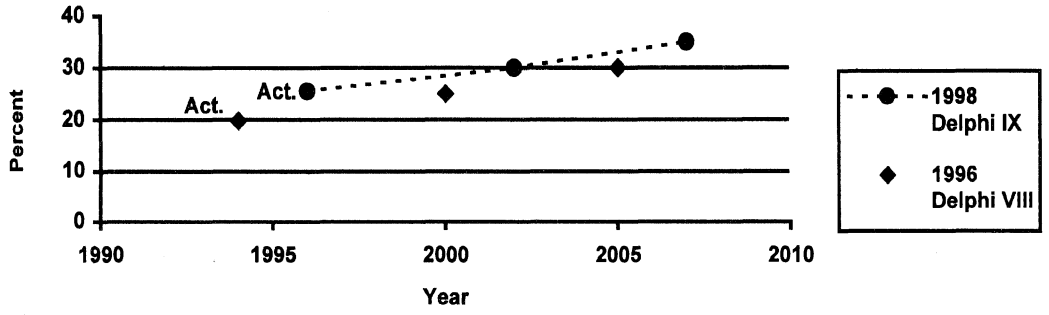
There is general agreement between the current and past surveys with regard to application of IL-6 engines in light trucks. The decrease forecast in previous surveys has not occurred to date, however, as evidenced by the actual data for 1992-1996. Actual data were not supplied with the 1992 Delphi VI survey, which may explain the somewhat high forecasts for that survey.

The current forecast for 60° V-6 engines in passenger cars and light trucks is compared to the 1996 Delphi VIII survey in the following graphs.

60-Degree V-6 Passenger Car Engine Forecasts



60-Degree V-6 Light Truck Engine Forecasts



The use of 60° V-6 engines has increased at a rate greater than forecast in the 1994 Delphi VIII survey for both passenger cars and light trucks. The forecast trend for the future is similar between the two surveys, however.

Strategic considerations

The primary advantage of the IL-6 design is outstanding balance characteristics. Cost is also an advantage, depending on the valvetrain configuration. These advantages are outweighed by packaging considerations in most applications. Crush distance from the front of the vehicle is also a concern for a frontal crash. One of the deomestic manufacturers is reported to be developing a new in-line six-cylinder engine for light trucks.

The superior balance characteristics of the 60° V-6 as compared to the 90° V-6 are the primary reason for the trend towards 60° designs. A balance shaft is required in a 90° V-6 to provide satisfactory smoothness at low speeds. This adds cost, weight, and complexity to the engine that is not required with the 60° V-6 design.

For vehicle packaging considerations, the lower profile of the 90° engine allows a lower hood line, whereas engine width is increased.

TECH-53. What percentage of North American-produced passenger car engines will incorporate the following number of valves per cylinder in 2002 and 2007?

		Median Response		Interquartile Range	
Valve Configurations	**1996***	**2002**	**2007**	**2002**	**2007**
Two valves per cylinder	55.4%	45%	35%	40/50%	30/40%
Three valves per cylinder	0	1	3	0/3	0/5
Four valves per cylinder	44.6	53	60	50/60	55/65
Five valves per cylinder	0	0	0	0/0	0/0

* **Source**: Ward's Automotive Reports, Feb. 3, 1997.

Selected edited comments

- Three valves may come into play with D.I. engines.
- Variable valve timing might ultimately be a bigger issue than the number of valves.

Discussion

Panelists forecast that the use of four-valve-per-cylinder engines in passenger cars will increase from 45 percent currently to 60 percent in 2007. In the same time frame, two-valve-per-cylinder engines are forecast to decrease from 55 percent currently to 35 percent.

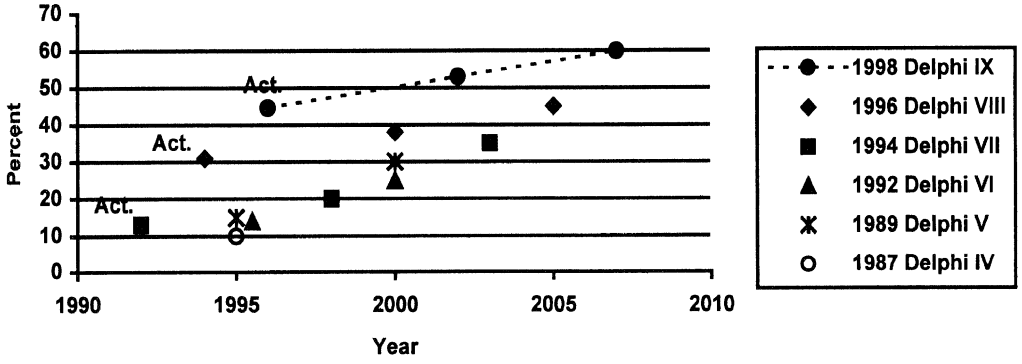
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

The current forecast for four-valve-per-cylinder engines is compared to that of previous forecasts in the following graph.

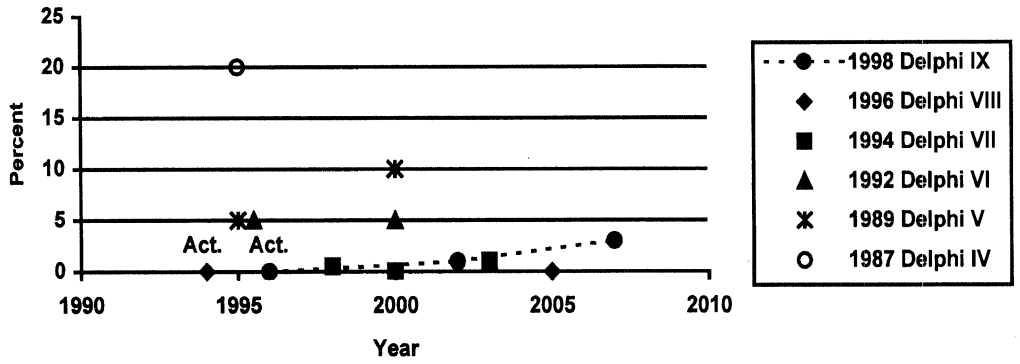
Four-Valve-per-Cylinder Engine Forecasts
North American Passenger Car Production



The application of four-valve-per-cylinder engines has increased at a rate greater than forecast by previous Delphi forecasts.

Early Delphi surveys forecast a significant use of three-valve-per-cylinder engines by the present time. The results of those surveys are compared to the current survey in the following graph.

Three-Valve-per-Cylinder Engine Forecasts
North American Passenger Car Production



Strategic considerations

The use of four-valve-per-cylinder engines has increased dramatically in recent years. This trend is forecast to continue in the future.

Four-valve-per-cylinder engines offer a significant power increase over two-valve-per-cylinder engines. Recent improvements in some two-valve-per-cylinder engines have reduced the gap between the two designs, however. The increased power available from a four-valve-per-cylinder engine may allow the use of a smaller engine in a vehicle, thereby improving fuel economy. This fuel economy improvement is somewhat offset by the increased parasitic valve-train losses and weight of a four-valve- per-cylinder engine. Furthermore, vehicle fuel economy improvements may not be realized if the increased power is used only to improve vehicle performance, not reduce vehicle axle ratio and engine size. In many applications of four-valve-per-cylinder engines, engine size is not reduced and fuel economy is actually decreased.

Three-valve-per-cylinder engines were thought to have a bright future a few years back. This has not proven to be true. This design, which incorporates two inlet valves and one exhaust valve, provides nearly the power of a four-valve engine but at reduced cost. One panelist noted that there might be renewed interest in this design with direct injection engines.

Two-valve-per-cylinder engines have significant cost, weight and packaging advantages. Recent improvements in power may keep this design in production for some time to come. This is particularly important in this time of vehicle price concerns. Panelists forecast a significant decrease in two-valve engines in the next decade, however.

TECH-54. What percentage of North American-produced passenger car engines will utilize the following valvetrain configurations in 2002 and 2007?

		Median Response		Interquartile Range	
Valvetrain Configurations	**1996***	**2002**	**2007**	**2002**	**2007**
"V" Engine Configurations					
Push rod	67.4%	60%	50%	52/65%	40/60%
Single overhead cam	17.0	20	25	18/20	20/28
Dual overhead cam	15.6	20	23	16/20	20/30
No cam (electromagnetic actuation)	0	0	0	0/0	0/3
Total	100%				
"In-Line" Engine Configurations					
Push rod	9.7%	5%	5%	5/9%	0/8%
Single overhead cam	34.4	35	35	30/37	26/40
Dual overhead cam	55.9	60	60	55/60	54/65
No cam (electromagnetic actuation)	0	0	0	0/0	0/2
Total	100%				

***Source:** Ward's Automotive Reports, Feb. 3, 1997.

Selected edited comments

- Cost/mass would suggest SOHC as the logical replacement for aging push-rod engines as they become obsolete and eventually get replaced.

Discussion

Panelists forecast a decrease in push rod engines and an increase in overhead cams in both "V" and "In-Line" engines in the next decade. Only 5 percent of in-line engines are forecast to have push rods by 2007. The use of push rods in "V" engines is forecast to decrease from 67 percent currently to 50 percent in 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

There was no differentiation between "V" and "In-line" engines prior to the 1996 Delphi VIII survey. Results from surveys prior to Delphi VIII are shown in the following table.

Valvetrain configurations	1995			1998	2000		2003
	Delphi IV	Delphi V	Delphi VI	Delphi VII	Delphi V	Delphi VI	Delphi VII
	1987	1989	1991	1993	1989	1991	1993
Push rod	30%	60%	45%	49%	60%	30%	35%
Single overhead camshaft	50	30	45	35	30	50	40
Dual overhead camshaft	20	10	10	15	10	18	20
No camshaft (e.g. electromagnetic)	—	—	0	0	—	2	1

Results from the current and previous survey, in which results are comparable, are shown in the following table.

Forecast for year →	1994	1996	2000	2002	2005	2007
Forecast →	Delphi VIII 1996	Delphi IX 1998	Delphi VIII 1996	Delphi IX 1998	Delphi VIII 1996	Delphi IX 1998
"V" Engine Configurations						
Push rod	68.5%	67.4%	60%	60%	50%	50%
Single overhead cam	24.0	17.0	30	20	30	25
Dual overhead cam	7.5	15.6	10	20	15	23
"In-Line" Engine Configurations						
Push rod	15.6	9.7	10	5	5	5
Single overhead cam	46.7	34.4	49	35	47	35
Dual overhead cam	37.7	55.9	40	60	45	60

There is good agreement between the two surveys regarding the penetration of push-rod engines. However, there is a difference in the distribution between single and dual overhead cams. The current survey forecasts significantly higher use of dual overhead cams than was forecast in Delphi VIII. This is likely because the baseline changed significantly between the two surveys.

Strategic considerations

Overhead cam engines generally allow a more optimum combustion chamber shape, and provide the capability of more rapid opening and closing of the valves because of the lower weight of the valvetrain. Overhead cam engines are also capable of higher operating speeds because of the lighter weight of the valvetrain. In recent years, however, there have been a number of advancements with push rod engines that allow them to more closely approach the performance of overhead cam engines. One of these advancements is the use of a steel camshaft, which can operate at the higher stress levels caused by the weight of the valvetrain. This allows a more rapid acceleration of the valve.

Dual overhead camshafts add significant weight to an engine and also increase engine friction

losses. They do, however, provide for maximum engine performance, although this performance level can be approached with a single overhead cam operating four valves off of one cam through linkages. Dual overhead cams are particularly troublesome in engines with a "V" configuration because the cylinder head becomes very large. This creates packaging problems.

In a "V" engine configuration, two or four overhead cams are required compared to one for a push rod engine. This adds considerable weight and cost. For this reason, push rod engines are forecast in half of the "V" engines in 2007.

Push-rod engines are used in most truck applications because of the relatively low cost. It is also possible to develop a high-torque push-rod engine that is well suited to truck applications. Overhead cam engines are beginning to appear in some light trucks, however. The competition between valve actuation technologies will be interesting to watch in trucks.

Future tougher emission standards could have an impact on valvetrain configuration because of the effect on combustion chamber characteristics and other factors. This may accelerate the move to overhead cam engines.

TECH-55. What percentage of North American-produced passenger car engines incorporate the following technical features currently and will in 2002 and 2007?

Advanced Engine Features	Median Response			Interquartile Range		
	Current Est.	2002	2007	Current Est.	2002	2007
Roller lifters						
% of DOHC engines	15%	40%	60%	15/20%	30/40%	40/65%
% of push rod engines	50	65	80	50/58	60/71	70/90
% of SOHC engines	25	45	60	25/30	30/50	40/70
Balance shaft (% of four-cylinder engines)	25	35	40	25/25	30/40	30/50
Balance shaft (% of 90° six-cylinder engines)	25	40	45	20/25	30/40	30/50
Hollow camshaft	10	15	20	4/20	10/46	13/60
Powdered metal cam and gears	5	11	20	4/10	7/38	10/50
Variable timing control	3	10	25	2/5	5/20	15/30
Variable lift control	1	5	10	0/3	2/10	5/18
Variable valve phasing	1	5	10	0/5	2/10	5/20
Lighter valves (20% or more)	2	10	15	0/9	2/25	10/40

Selected edited comments

- 90 degree 6-cylinders will continue to go away.
- Fuel economy will once again trade off against cost/affordability, but I would expect the trend toward willingness to pay for less friction (roller lifters) to continue.
- I counted roller-finger-follower valvetrains as "roller lifters", even though the lifter itself does not contain roller elements. Roller-finger-follower valvetrains are required for many variable valve actuation (VVA) systems.
- This assumes roller lifter usage included consideration for direct acting valvetrain using bucket tappets which can not apply roller technology. Roller lifter categories would be 100 percent if the direct acting style were separated out from the DOHC and SOHC considerations.

Discussion

Panelists' forecasts for passenger car engines in 2007 are that:

- Balance shafts will be used on 40 percent of four-cylinder engines and 45 percent of 90° six-cylinder engines.
- Less than 25 percent of engines will have hollow camshafts, powdered metal cam and gears, variable timing control, variable lift control, variable valve phasing or 20 percent lighter valves.
- Most engines will have roller lifters (80 percent of push rod engines).

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

Results for the current survey are compared to previous surveys where results are comparable in the table below.

Forecast for year →	1995		1997	1998	2000		2002	2003	2005	2007
Survey → Technical Features	1992 Delphi VI	1996 Delphi VIII	1998 Delphi IX	1994 Delphi VII	1992 Delphi VI	1996 Delphi VIII	1998 Delphi IX	1994 Delphi VII	1996 Delphi VIII	1998 Delphi IX
Roller lifters										
% of DOHC	n/a	15%	15%	n/a	n/a	25%	40%	n/a	35%	60%
% of push rod	n/a	50	50	n/a	n/a	65	65	n/a	80	80
% of SOHC	n/a	20	25	n/a	n/a	30	45	n/a	40	60
Balance shaft (% of 4-cylinder engines)	25%	20	25	20%	30%	35	35	25%	45	40
Balance shaft (% of 90 deg. 6-cylinder)	n/a	25	25	n/a	n/a	40	40	n/a	50	45
Hollow camshaft	10	5	10	10	15	15	15	15	30	20
Powdered metal cam and gears	10	5	5	3	20	10	11	10	20	20
Variable timing	2	n/a	3	5	10	5	10	10	15	25
Variable lift	1	n/a	1	1	5	1	5	10	5	10
Lighter valves	n/a	n/a	2	n/a	n/a	10	10	n/a	20	15

Responses for the current survey are in general agreement with past surveys with the exception that the current survey forecasts higher penetration of:

- Roller lifters in DOHC engines
- Roller lifters in SOHC engines
- Variable valve timing

Strategic considerations

Balance shafts, 90 degree six cylinder engines: Balance shafts on 90 degree six-cylinder engines reduce a first order moment unbalance with a balance shaft running at engine speed. The disadvantages are similar to those of four-cylinder engines, except the friction losses and potential warranty increases are reduced because the balance shaft on a six-cylinder engine runs at engine speed.

Balance shafts, four-cylinder engines: Panelists forecast a significant increase in penetration of this feature. Balance shafts on four-cylinder engines run at twice engine speed. On four-cylinder engines they significantly reduce noise and vibration, particularly at high engine speeds on engines with a displacement greater than 2.0 liters. Disadvantages include increased cost and reduced fuel economy as a result of increased friction losses, increased weight, and potentially increased warranty cost. In spite of these disadvantages, panelists forecast increased use.

Hollow camshaft: Penetration of this weight-saving feature is forecast to to increase to 20 percent by 2007.

Powdered metal cam and gears: Powdered metal can reduce machining requirements, and thereby cost.

Roller lifters: Panelists forecast a significant increase in the use of roller lifters through 2007. The advantage of this feature is an approximate 2 percent improvement in fuel economy. The feature will contribute to manufacturers' CAFE. Cost and increased weight are disadvantages.

Variable lift control: This has similar advantages and disadvantages as variable timing control.

Variable timing control: Variable timing control can improve power without sacrificing idle quality or HC emissions. It can also be used to improve NOx emissions. Cost, weight, and potential increased warranty are disadvantages. Honda utilizes variable valve timing and lift control on the inlet valve on Acura four passenger car engines and on both inlet and exhaust on the NSX engine.

Variable valve phasing: This has similar advantages and disadvantages as variable timing control.

TECH-56. Please indicate in what year the following technologies will see limited application (<5 percent) in passenger cars or light-duty trucks, and what year the technology will see a 25 percent application rate.

	Median		Interquartile Range	
Technology	Limited application	25% application	Limited application	25% application
Two-stroke spark-ignited engine	2005	2012	2002/2005	2010/2015
Active/semiactive engine mounts	2002	2009	2000/2005	2005/2014

Other Responses:

25% application — never for each (3 responses)

Never for 25% application of engine mounts (2 responses)

Two stroke — never (3 responses)

Selected edited comments

- I don't believe that two-stroke engines will ever be used in the North American market due to emissions requirements.
- I would not bet on either of these technologies. Coming LEV/ULEV/S-LEV emission standards would imply the "window of opportunity" for two strokes is closing fast. The exotic engine mounts would most logically offer the most benefit on L3/L4 applications which won't support the cost. Limited benefit vs. cost will constrain usage in six- and eight-cylinder applications.
- Semiactive engine mounts cost money. The same effect can be had other ways for less.
- The 2005 answer for two-stroke is on a global basis, it will never see an application of more than some novel application here in North America.
- Too much history and knowledge of four-stroke for two-stroke to catch up. Active engine mounts could save 90° engines where space is significant. They are a boon to NVH, in any event, when perfected.

Discussion

Panelists forecast that two-stroke spark ignition engines and active/semiactive engine mounts will not see an application rate of 25 percent until 2012 and 2009 respectively.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was first asked in this format in the 1996 Delphi VIII survey. A comparison of results of the two surveys is shown in the following table.

Technology	Limited Application		25% Application	
	1996 Delphi VIII	1998 Delphi IX	1996 Delphi VIII	1998 Delphi IX
Two-stroke spark-ignited engine	2001	2005	2010	2011
Active/semiactive engine mounts	1999	2002	2005	2009

Results of the two surveys are similar, although the current survey forecasts a later introduction of both technologies.

Strategic considerations

The two-stroke spark-ignition engine has the advantage of high specific power. Considerable weight and space savings could result from the application of this design. Emissions control and durability problems have kept this engine from seeing production. Engine noise has been another problem. Panelists do not see early solutions to these problems.

Active/semiactive engine mounts are beneficial for isolation of engine noise and vibration. High cost is the major obstacle. This technology is forecast for 25 percent of vehicles by 2009.

Of course, technological developments in the next few years could alter the forecast.

TECH-57. What percentage of current North American-produced engines will undergo major redesign (> 30 percent of the investment cost of a new engine) by 2002 and 2007?

	Median		Interquartile Range	
North American-Produced Engines	2002	2007	2002	2007
4-cylinder engine	20%	50%	20/30%	40/60%
V-6 engine	20	45	20/25	40/50
V-8 engine	15	30	10/20	23/40

Selected edited comments

- CAFE legislation is likely to drive substantial redesign in the long term.
- CAFE legislation will continue to obsolete current engines and drive substantial redesign/reconfiguration in the long run.
- New emission requirements will force some major redesigns. V-8s will be somewhat protected by light-truck installation.
- V-8s will require the most rework to retain the customer-desired features, but still meet the ever tighter emissions regulations and anticipated CAFE increases.

Discussion

Panelists forecast that 50 percent of four-cylinder engines, 45 percent of V-6 engines and 30 percent of V-8 engines will undergo major redesign by 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

Results of the current survey are compared to those of previous surveys in the following table.

By the year →	2000		2002	2003	2005	2007
Survey year →	1989	1991	1998	1993	1996	1998
Engine	Delphi V	Delphi VI	Delphi IX	Delphi VII	Delphi VIII	Delphi IX
4-cylinder engine	70%	65%	20%	50%	50%	50%
V-6 engine	65	60	20	60	50	45
V-8 engine	60	50	15	40	35	30

Comparisons to past surveys are difficult for this question in that it is not known how much redesign has been done since each of the past surveys. On a relative basis it can be stated, however, that current panelists expect slightly less major engine redesign in the next decade than did panelists of previous surveys.

Strategic considerations

Engine redesign activity has been high in the recent past and is forecast to remain so in the next decade. This activity will likely be directed at improving fuel economy and reducing exhaust emissions. The move to aluminum cylinder heads and blocks forecast in TECH-62a will also require significant design and development.

While much of the design may be directed at totally new engines, it is likely that continuous improvement of current designs will continue.

Many of the components or features covered previously in this survey will drive the design process. These include direct-injection spark-ignition engines, roller lifters, variable valve timing, balance shafts and new technology ignition systems.

Engine design has defined the brand character for many vehicles in the past. It is likely that this will continue, and manufacturers will strive to excel in engine design.

TECH-58. What percentage of North American-produced passenger cars and light trucks with spark-ignited engines will incorporate the following types of fuel management systems in 2002 and 2007?

		Median Response		Interquartile Range	
Passenger Cars Fuel Injection:	**1996***	**2002**	**2007**	**2002**	**2007**
Port or multipoint	98.2%	98%	90%	95/99%	84/97%
Throttle body (single point)	1.8	0	0	0/1	0/1
Direct cylinder injection	0	2	10	0/5	2/16
Total	100%				

		Median Response		Interquartile Range	
Light Trucks Fuel Injection:	**1996***	**2002**	**2007**	**2002**	**2007**
Port or multipoint	97.0%	97%	95%	95/98%	85/99%
Throttle body (single point)	3.0	1	0	0/2	0/1
Direct cylinder injection	0	1	5	0/5	0/15
Total	100%				

***Source:** Ward's Automotive Reports, Feb. 3 and Feb. 24, 1997.

Selected edited comments

- Emission regulations and type of catalyst system used are considerations.

Discussion

Panelists forecast that the vast majority of spark-ignited engines in passenger cars and light trucks will have port or multipoint fuel management systems in the next decade. Direct cylinder injection is expected to see some application by 2007, however, with application rates in passenger cars and light trucks of 10 and 5 percent respectively.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

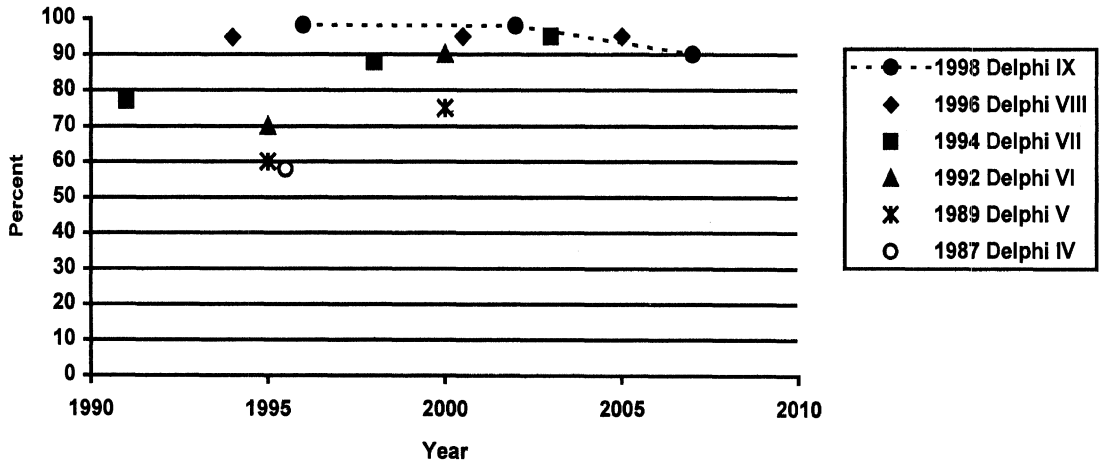
Trend from previous Delphi surveys

Passenger cars:

A comparison of the current survey to previous surveys for passenger cars is shown in the following table.

Passenger Car Fuel Management Systems				
Forecast for year	**Forecast**	**Port (multipoint)**	**Throttle Body**	**Direct cylinder injection**
1991 Est.	**1994 Delphi VII**	77%	23%	0%
1994 Est.	**1996 Delphi VIII**	95	5	0
1995	**1987 Delphi IV**	58	40	-
	1989 Delphi V	60	35	-
	1992 Delphi VI	70	30	-
1996 Est.	**1998 DELPHI IX**	98	2	-
1998	**1994 Delphi VII**	88	10	-
2000	**1989 Delphi V**	75	25	-
	1992 Delphi VI	90	10	
	1996 Delphi VIII	95	2	1
2002	**1998 Delphi IX**	98	0	2
2003	**1994 Delphi V**	95	2	-
2005	**1996 Delphi VIII**	95	0	5
2007	**1998 Delphi IX**	90	0	10

Passenger Car Port Fuel-Injection Forecasts



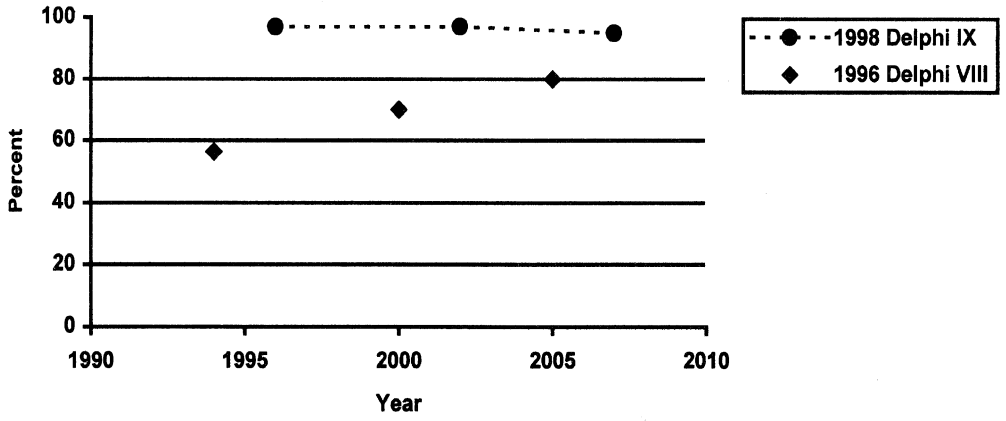
The current estimate for port fuel injection of 98.2 percent is considerably higher than forecast in earlier Delphi surveys for this time frame. Likewise, the current estimate for throttle body injection of 1.8 percent is considerably lower than forecast in earlier Delphi surveys.

Light trucks:

This question was not asked for light trucks prior to the 1996 Delphi VIII survey. Results from the current survey are compared to those of Delphi VIII in the following table.

Light Truck Fuel Management Systems				
Forecast for year	**Forecast**	**Port (multipoint)**	**Throttle Body**	**Direct cylinder injection**
1994 Est.	**1996 Delphi VIII**	56%	40%	0%
1996 Est.	**1998 Delphi IX**	97	3	0
2000	**1996 Delphi VIII**	70	20	5
2002	**1998 Delphi IX**	97	1	1
2005	**1996 Delphi VIII**	80	10	6
2007	**1998 Delphi IX**	95	0	5

Light Truck Port Fuel-Injection Forecasts



The current application rate of port fuel injection on light trucks is considerably higher than forecast only two years ago in Delphi VIII.

Strategic considerations

There have been rapid, dramatic changes in fuel management systems for both passenger cars and light trucks in the last twenty years. In 1980, carburetors were used on most passenger cars and light trucks. During the early 1980s throttle body injection became widely used on both passenger cars and light trucks. By 1990, carburetors had disappeared from passenger car engines, and port fuel injection dominated over throttle body injection. Port fuel injection is currently used on almost all passenger cars and light trucks.

Emissions control, fuel economy and performance were the driving forces behind this dramatic technology shift. Carburetors did not provide adequate control for closed loop emission systems. Throttle body injection had a lower cost than port fuel injection, and rapidly replaced carburetors. Port fuel injection provides superior fuel control to throttle body injection, and soon replaced throttle body injection as emission standards became more stringent.

Direct cylinder injection is forecast to have limited application in passenger cars and light trucks

in the next decade. One Japanese manufacturer has stated that they are planning to use direct-injected gasoline engines in all of their passenger cars, with a phasein to Japan, Europe, and then the United States. This system allows development of superior fuel economy to port fuel injection.

The controversy over global warming and the economic risks associated with importing large quantities of oil may accelerate the application of direct fuel injection. A manufacturer that produces engines with direct injection may have a competitive advantage. This is an area that should be watched closely because it is by no means certain that this technology will be applicable with U.S. emissions standards and larger vehicles. Both NOx and hydrocarbon emissions are difficult to control. High levels of NOx control require particularly challenging technologies such as a reducing catalyst that will work in an oxygen-rich environment.

TECH-59. What are the technical challenges with regard to development of direct-injection spark-ignition engines?

Responses:

Biggest challenge is fuel quality, especially sulfur content, causing injector deposits (3 responses)

Cost/investment (8 responses)

Cylinder pressure

Design sensitivity to minor production variations

Drivability via existing control system technology

Durability

Durable, high-pressure injectors that retain control over the vehicle's life (2 responses)

Electronic cost and reliability

Elimination of misfires

Emissions and lean NOx catalysts (20 responses)

For all DI, increase in the fuel pressure is required to flow fuel during the compression stroke. Design of combustion chamber and piston top must promote mixing.

Fuel distribution, knock, particulates (2 responses)

Fuel flow injectors, heat at injector, soot in exhaust, carbon build up on piston, preignition from carbon, system pressure and noise, ring wear, piston wear, spark plug fouling

Fuel pump noise

Fuel quality and consistency for cleanliness, lubricity, density and viscosity

High-pressure fuel delivery systems from the tank to the injectors to support direct Injection (3 responses)

High-pressure fuel -ump durability (6 responses)

In North America with $1.20/gal. gasoline it is hard to justify anything that may increase cost because there is no payback for the customer even if it does have significant F/E improvements.

Injector driver electronics

Keeping the injectors cool and lubricated at this point of entry in the combustion chamber is a challenge. (3 responses)

Lean combustion, fine droplet atomization

Long term HC stability, deposits

Lubrication

Packaging to some degree

Reliability, control

Safety of high pressure fuel distribution systems, i.e., fire due to a leak

Seat life

Significant increase in cost and the reliability of the fuel injection system and overall reliability of the engine

Timing, resistance to change

Two-stroke engines; vapor lock; sealing, maintaining compression

Unfavorable torque—curve in comparison with direct-injected diesel engines

Uniformity of mixture as related to ignition and fuel efficiency; spark front propagation

Wide A/F range control sensors; HC/NOx emissions

Discussion

Panelists noted several technical challenges with regard to development of direct- injection

spark-ignited engines. The most frequently mentioned challenges are emissions control, cost/investment and high-pressure fuel pump durability.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This is the first time that this question has been included in a Delphi survey.

Strategic considerations

The strategic considerations noted in TECH-58 with regards to direct-injected spark-ignited engines apply to this question also. A formidable list of challenges has been noted by panelists. It is likely that these challenges will be aggressively addressed by manufacturers, however, to allow the production of this highly fuel-efficient engine.

TECH-60. What percentage of North American-produced spark-ignited engines for passenger cars will be either supercharged or turbocharged in 2002 and 2007?

		Median Response		Interquartile Range	
Spark-Ignited Engines	**1996***	**2002**	**2007**	**2002**	**2007**
Supercharged	0.4%	1%	1%	0/1%	0/5%
Turbocharged	0.1	1	1	0/1	0/5

***Source:** Ward's Automotive Reports, Feb. 3, 1997.

Selected edited comments

- Based on the development work ongoing, a significant reduction in supercharger system cost will occur around 2002, and by 2007, a significant portion of engines (> 20 percent) will be supercharged.
- Cost/complexity considerations would tend to preclude boosted engines from more than select "niche" usage in mainstream vehicles.
- Four-valve engines are more reliable and less costly for gains realized.
- Supercharger may be used on some hybrid applications.
- Too expensive for wide utilization.

Discussion

Panelists forecast that 1 percent of passenger car engines will be turbocharged and 1 percent will be supercharged by 2007 compared to less than .5 percent currently.

Manufacturer/supplier comparison

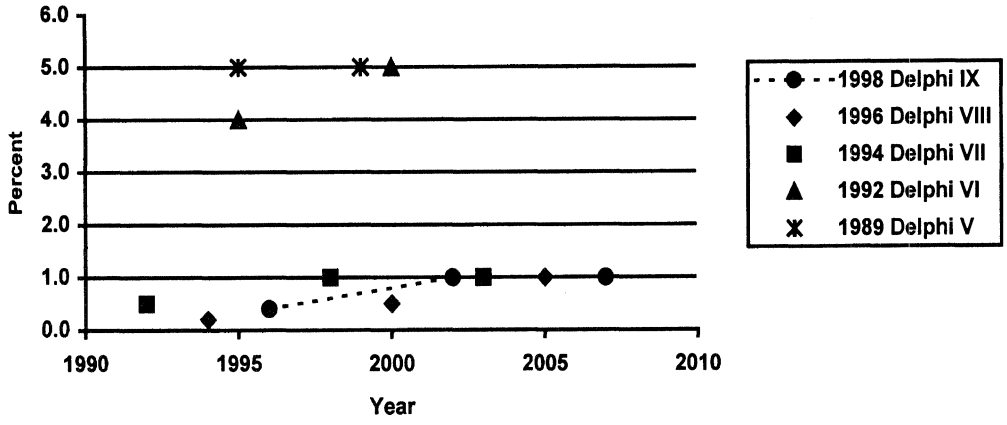
There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

In the 1979 Delphi I survey, panelists forecast that 25 percent of spark-ignited passenger car engines would be turbocharged by 1990. The 1981, 1984 and 1987 Delphi panelists forecast 10 percent penetration of turbocharging by 1990.

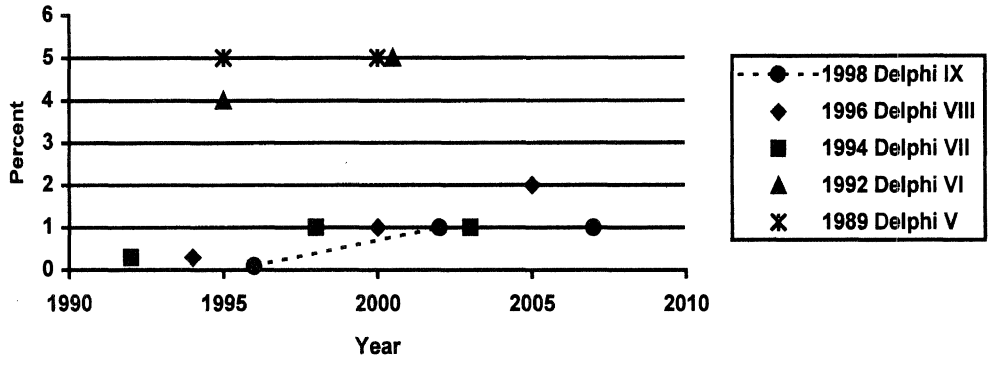
The results of the current survey are compared to those of the previous four surveys in the following graphs.

Turbocharged Engine Forecasts
North American Passenger Car Production



Results of the current survey for turbochargers are similar to those of the past three surveys. However, actual current application is below expectations based on recent surveys. As noted above, early surveys forecast much greater use of turbochargers than has materialized and much greater than is forecast in the current survey.

Supercharged Engine Forecasts
North American Passenger Car Production



The current and past forecasts for superchargers are very similar to those of turbochargers. The discussion above for turbochargers applies here also.

Strategic considerations

Early Delphi surveys forecast a high penetration for turbochargers and superchargers. Since those early surveys four-valve-per-cylinder engines have become commonplace. Manufacturers have determined that power increases that are made from the application of turbochargers and superchargers are also available through the use of four-valve-per-cylinder engines. Furthermore, cost, packaging and durability issues are less of a problem. The high low-end torque produced by turbochargers and superchargers is not available with four-valve engines, however. Effectively both devices extend or amplify engine displacement on demand.

One of the panelists commented that a supercharger is under development that has the potential for significantly lower cost. Supercharger technology should be watched closely for new developments.

Inlet boost through either supercharging or turbocharging is always an option to extend the power capability of a given engine. In most cases it can be brought to market with an existing engine more quickly and at lower cost than developing a new engine.

TECH-61. What percentage of North American-produced passenger cars and light trucks with spark-ignited engines will incorporate the following ignition system features in 2002 and 2007?

		Median Response		Interquartile Range	
Ignition System Features **Passenger Cars**	**1996***	**2002**	**2007**	**2002**	**2007**
Coil-on-plug designs	n/a	10%	20%	5/14%	10/40%
Cylinder pressure control of ignition	0	1	4	0/2	1/10
Distributorless ignition systems	64.0%	75	90	70/80	80/95
Individual cylinder control of ignition timing	0	5	10	1/10	4/20
Knock/adaptive control	62.8	70	80	70/80	75/95
Light Trucks					
Coil-on-plug designs	n/a	10%	20%	0/15%	5/30%
Cylinder pressure control of ignition	n/a	0	2	0/2	0/10
Distributorless ignition systems	n/a	70	80	28/75	50/90
Individual cylinder control of ignition timing	n/a	2	5	0/10	0/23
Knock/adaptive control	n/a	70	80	50/80	60/95

***Source:** Ward's Automotive Reports, Feb. 3, 1997.

Selected edited comments

- "Coil on Plug" for my rating includes "Coil NEAR Plug" which have a very short or no secondary leads.
- Coil on Plug—distributorless.

Discussion

Panelists forecast that distributorless ignition systems and knock/adaptive control will be used on most passenger car and light truck engines by 2007. Limited applications of cylinder pressure control of ignition and individual cylinder control of ignition timing are forecast to appear by 2007.

Manufacturer/supplier comparison

Responses for manufacturers and suppliers are statistically significantly different for the areas noted in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

Ignition System Features				
	2002 Mean		2007 Mean	
	Mfr.	Supp.	Mfr.	Supp.
Passenger Cars				
Distributorless ignition	78%	73%	-	-
Light Trucks				
Distributorless ignition	65	48	82	61
Knock/adaptive control	71	50	-	-

Manufacturers forecast significantly higher use of distributorless ignition and knock/adaptive control in light trucks than suppliers.

Trend from previous Delphi surveys

Results of the current survey for passenger cars are compared to those of past surveys in the following table.

Passenger Car Ignition System Features						
Forecast for year	**Forecast**	**Coil-on-Plug Designs**	**Cylinder Pressure Control of Ignition**	**Distributor-less Ignition**	**Individual Cylinder Control of Ignition**	**Knock/ Adaptive Control**
1991 Est.	**1994 Delphi VII**	n/a	0%	46%	0%	32%
1994 Est.	**1996 Delphi VIII**	n/a	0	46.2	0	44.9
1995	**1987 Delphi IV**	-	-	50	20	55
	1989 Delphi V	5	-	40	40	30
	1992 Delphi VI	5	-	50	40	40
1996 Est.	**1998 Delphi IX**	n/a	0	64	0	62.8
1998	**1994 Delphi VII**	5	1	60	5	40
2000	**1989 Delphi V**	15	-	75	75	60
	1992 Delphi VI	10	-	75	60	65
	1996 Delphi VIII	5	0.5	60	2	55
2002	**1998 Delphi IX**	10	1	75	5	70
2003	**1994 Delphi VII**	10	5	80	15	60
2005	**1996 Delphi VIII**	10	3	75	9	70
2007	**1998 Delphi IX**	20	4	90	10	80

Forecasts for the current survey for passenger cars are generally in agreement with those of past surveys, with the exception of individual cylinder control of the ignition. Earlier surveys forecast 20 to 40 percent application by 1995. In fact, there is no production application at this time.

Ignition system features for light trucks were covered in the 1996 Delphi VIII forecast for the first time. The results of the current survey are compared to those of Delphi VIII in the following table.

Light Truck Ignition System Features						
Forecast for year	**Forecast**	**Coil-on-Plug Designs**	**Cylinder Pressure Control of Ignition**	**Distributor-less Ignition**	**Individual Cylinder Control of Ignition**	**Knock/ Adaptive Control**
2000	**1996 Delphi VIII**	3%	0%	46%	0%	40%
2002	**1998 Delphi IX**	10	0	70	2	70
2005	**1996 Delphi VIII**	10	0.3	60	5	50
2007	**1998 Delphi IX**	20	2	80	5	80

Forecasts for the current survey for light trucks are generally in agreement with those of past surveys, with the exception of knock/adaptive control of ignition. The current survey forecasts higher penetration for knock/adaptive control than was forecast in 1996 Delphi VIII.

Strategic considerations

Coil-on-plug designs offer improved reliability by eliminating high-voltage secondary wiring. This is important, with the requirements for 100,000-mile emissions durabilty. Increased cost and packaging are restraining factors at this time.

Cylinder pressure control of ignition could be applied to each cylinder individually and offers the potential to reduce cylinder-to-cylinder variation problems which result from manufacturing variability, differences in cylinder deposits and fuel/air mixture variation from cylinder to cylinder and cycle to cycle. This technology has been desired for some time but has been difficult to accomplish with present cost and reliability requirements.

Distributorless ignition systems offer improved reliability and are forecast to be on most engines by 2007.

Individual cylinder control of ignition timing could be accomplished by measurement of individual cylinder knock or cylinder pressure measurements. The benefits can be those described under cylinder pressure control of ignition.

Knock adaptive control of ignition allows higher compression ratio to be used. This results in improved performance and fuel economy.

TECH-62a. What percentage of North American-produced passenger car and light truck engines in 2002 and 2007 will utilize cast iron or aluminum cylinder heads and blocks?

		Median Response		Interquartile Range	
Passenger Cars Material	**1996***	**2002**	**2007**	**2002**	**2007**
Heads					
Cast iron	13.7%	10%	5%	10/11%	4/10%
Aluminum	86.3	90	95	90/90	90/96
Total	100%				
Blocks					
Cast iron	83.5%	77%	65%	70/80%	50/75%
Aluminum	16.5	24	35	20/30	25/50
Total	100%				

		Median Response		Interquartile Range	
Light Trucks Material	**1996***	**2002**	**2007**	**2002**	**2007**
Heads					
Cast iron	76.8	70%	60%	60/75%	40/70%
Aluminum	23.2	30	40	25/40	30/60
Total	100%				
Blocks					
Cast iron	97.4	93%	85%	85/95%	70/90%
Aluminum	2.6	7	15	5/15	10/30
Total	100%				

***Source:** Ward's Automotive Reports, Feb. 3 and Feb. 24, 1997 and OSAT estimates.

Selected edited comments

- A significant increase in the use of high-tech aluminum engines is expected (as much as 50 percent by 2010, of all vehicles).
- The greater use of aluminum is required to reduce weight to improve fuel economy (cast iron liners with aluminum blocks).
- There will be more pressure for truck fuel economy, driving weight reduction.
- This assumes a lot of the older cast iron 6s and 8s will go away by 2007 due to fuel economy.

Discussion

Panelists forecast that the use of aluminum for cylinder heads and blocks will increase in the next decade. For passenger cars, aluminum is forecast for 95 percent of cylinder heads and 35 percent of cylinder blocks by 2007.

Manufacturer/supplier comparison

Responses for manufacturers and suppliers are statistically significantly different for the areas noted in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

Cylinder Block Material				
	2002 Mean		2007 Mean	
	Mfr.	Supp.	Mfr.	Supp.
Passenger Cars				
Cast iron	71%	77%	51%	66%
Aluminum	29	23	49	34
Light Trucks				
Cast iron	-	-	71	83
Aluminum	-	-	29	17

Manufacturers forecast significantly higher use of aluminum in cylinder blocks than suppliers.

Comparison of forecast: MAT-27

There is a statistically significant difference in mean responses between technology and materials panelists for the cylinder blocks in passenger cars and cylinder heads in light trucks in the years shown in the following table.

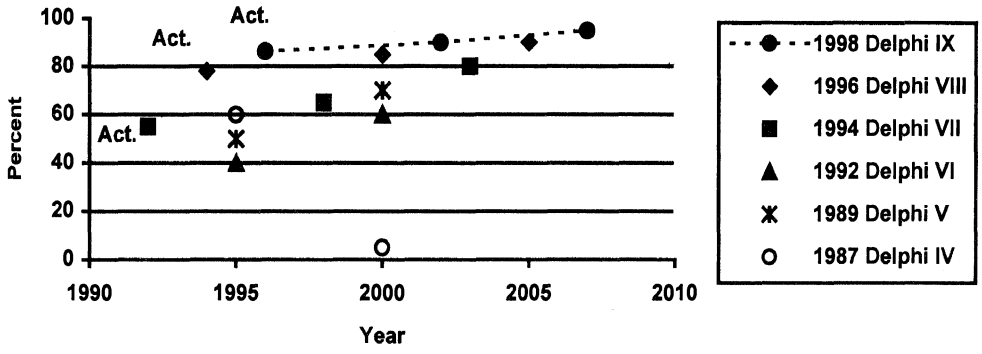
Cylinder Block and Head Material - Percent				
	2002		2007	
	TECH	MAT	TECH	MAT
Passenger Car Blocks				
Cast iron	74	69	59	48
Aluminum	26	31	41	52
Light Truck Heads				
Cast iron	65	53	52	34
Aluminum	35	47	47	66

Technology panelists forecast a lower use of aluminum in passenger car cylinder blocks and light truck cylinder heads than do materials panelists.

Trend from previous Delphi surveys

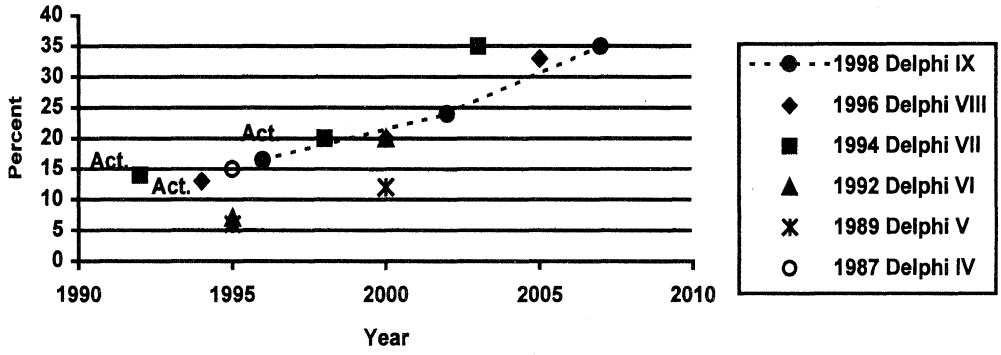
The results of the current survey for passenger cars are compared to those of past surveys in the following graphs.

Aluminum Cylinder Head Forecast - Passenger Cars



The current estimate for aluminum cylinder heads is higher than forecast in previous surveys for this date.

Aluminum Cylinder Block Forecasts - Passenger Car



The current forecast is in general agreement with previous forecasts for the use of aluminum in cylinder blocks.

The forecast use of aluminum in light truck cylinder heads and blocks was first included in the 1996 Delphi VIII survey. The results of the current survey are compared to those of Delphi VIII in the following table.

Light Truck Aluminum Cylinder Heads and Blocks			
Forecast/ Estimate for year	**Forecast**	**Cylinder Heads**	**Cylinder Blocks**
1994	**1996 Delphi VIII Est.**	20%	5%
1996	**1998 Delphi IX Est.**	23.2	2.6
2000	**1996 Delphi VIII**	30	10
2002	**1998 Delphi IX**	30	7
2005	**1996 Delphi VIII**	47	15
2007	**1998 Delphi IX**	40	15

There is good agreement between the current forecast and Delphi VIII for the use of aluminum in light truck cylinder heads and blocks.

Strategic considerations

The use of aluminum in passenger car engine cylinder heads has accelerated at a rate greater than forecast in previous Delphi surveys. Aluminum is also forecast to increase in use in passenger car cylinder blocks and light truck cylinder heads and blocks.

Manufacturers are making the commitment to lower weight, in spite of the delayed increase in CAFE standards and the cost penalty associated with this material. Changing from cast iron to aluminum requires a significant lead time, and manufacturers are not able to wait until CAFE requirements change in order to make the change. Also, the shift by consumers from passenger cars to sport utility vehicles and from small passenger cars to larger ones has taxed the manufacturers' ability to meet current CAFE standards. Replacing cast iron with aluminum is one strategy to address CAFE problems.

The use of aluminum for engine cylinder heads and blocks may have synergistic effects on weight savings. Lighter engines may allow the use of lighter suspension systems, engine cradles, tires, and brakes.

The noise damping characteristics of aluminum must be considered when switching from cast iron. Cast iron has excellent noise-damping characteristics. In many cases, accessory brackets must be stiffened, thereby adding weight, when changing from cast iron to aluminum for cylinder heads and blocks. Many engines in production today, however, verify that it is possible to produce a quiet engine with aluminum cylinder heads and blocks. Attention to detail is critical, however.

Thin-wall casting of cast iron has resulted in significant engine weight savings in recent years. In spite of the progress in this area, however, panelists forecast a major shift to aluminum.

TECH-62b. What percentage of aluminum blocks forecast in TECH-62a will be sleeved, unsleeved and coated, and unsleeved?

		Median Response		Interquartile Range	
Aluminum Block Engines	**Est. 1996***	**2002**	**2007**	**2002**	**2007**
Sleeved	100%	99%	95%	95/100%	80/99%
Unsleeved and coated	0	1	5	0/5	1/17
Unsleeved	0	0	0	0/0	0/0
Total	100%				

***Source:** OSAT estimates.

Selected edited comments

- A low-cost coating breakthrough is needed to enable the mass savings associated with sleeveless construction.
- "Coated" includes steel bore sprayed onto the Aluminum bores.
- For sleeved and coated 2002 and 2007, coating technology will be reaching maturity, Unsleeved/coated engines are expected to represent at least 50 percent of aluminum engines by the year 2010.

Discussion

Panelists forecast that 95 percent of aluminum cylinder blocks will be sleeved and 5 percent will be unsleeved and coated by 2007. This is in contrast to 100 percent sleeved today.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was first asked in the 1996 Delphi VIII survey. The results of the current survey are compared to those of Delphi VIII in the following table.

Sleeved Aluminum Cylinder Blocks		
Forecast for year	**1996 Delphi VIII**	**1998 Delphi IX**
1994	100%	
1996		100%
2000	98	
2002		99
2005	90	
2007		95

Panelists in the current survey forecast higher use of sleeved cylinder blocks in 2007 than those of the Delphi VIII survey.

Strategic considerations

There is a weight and cost savings associated with unsleeved and coated aluminum cylinder blocks compared to those that are sleeved. Unsleeved aluminum cylinder blocks have been in production in this country, most notably in the Chevrolet Vega in the 1970s. Early durability problems with this engine resulted in a poor reputation. The problems were resolved, but the reputation remained for some time.

The experience on the Vega may demonstrate that unsleeved cylinder blocks are more design-sensitive than those with cast-in liners. Manufacturers are reluctant to apply this technology, as evidenced by the low forecast use for 2007.

The comment of one panelist that "unsleeved/coated engines are expected to represent at least 50 percent of aluminum engines by year 2010" should be noted. This panelist may have insight or knowledge that is not commonly known in the industry.

TECH-63. What percentage of North American-produced passenger cars will use lean-burn technology with a NOx catalyst by 2007?

	Median Response	Interquartile Range
Lean-Burn Technology	**2007**	**2007**
With Nox catalyst to meet:		
Federal standards	20%	10/50%
California standards	25	10/75

Selected edited comments

- Federal and California emission standards will be almost the same by 2007, so if it works for federal, it will work for California. The only thing preventing wider spread use will be cost and customer demand.
- I would expect federal and California standards to converge by 2007. The key issue is catalyst development/durability.
- Lean NOx catalyst technology will not be robust enough for application (poisons, durability, temperature control).
- Major inhibitor for application of NOx catalyst is the sulfur content in gasoline. If the oil industry does not make a major effort to reduce sulfur in fuel, the probability of lean-burn technology usage in the United States will be significantly less.
- Providing there is a lean NOx catalyst.
- The technology is expensive, unreliable and, at the present, projections are that it is costly and may not be able to meet 150,000-mile/ULEV durability requirements. Significant breakthroughs are needed. If they materialize the above will be over 70 percent.
- This is another one of those technological "holy grails" that is always more than 30 years away.

Discussion

Panelists forecast that 20 percent of North American-produced passenger cars meeting federal standards in 2007 will use lean-burn technology with a NOx catalyst. Similarly, 25 percent of passenger cars meeting California standards will use this technology. The wide interquartile range spread in responses indicates uncertainty or differing approaches within the industry.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was first asked in this format in the 1994 Delphi VII survey. Previous surveys did not differentiate between Federal and California emission standards. The results of surveys prior to Delphi VII are shown in the following table.

For year →	1995			2000	
Lean-Burn Technology	Delphi IV	Delphi V	Delphi VI	Delphi V	Delphi VI
	1987	1989	1991	1989	1991
	20%	5%	5%	15%	8%

Results of the current and past two Delphi surveys are compared in the following table for federal and California standards.

Lean-Burn with NOx Catalyst			
Forecast for year	Forecast	Federal Standards	California Standards
2003	1994 Delphi VII	10%	10%
2005	1996 Delphi VIII	25	40
2007	1998 Delphi IX	20	25

Considering the large interquartile range in responses for the current survey, there is general agreement with past surveys on this issue.

Strategic considerations

Lean burn with a NOx catalyst offers the potential advantage for a 7 to 10 percent improvement in fuel economy, with throttling—and even more if throttling can be reduced. Toyota has developed a four-stroke, direct-injected gasoline engine with a lean-burn NOx catalyst for the Japanese market. This technology is also being pursued as part of the PNGV program in a coordinated effort between the U.S. Department of Energy's National Laboratories and USCAR's Low Emission Partnership (LEP).

A breakthrough in the development of NOx catalysts might lead to the rapid application of lean-burn technology although hydrocarbon emissions can also be a problem.

This technology may also be applicable to diesel engines and may allow the widespread use of diesel engines in North America.

The broad interquartile range in responses to this question suggests significant uncertainty or differences in approach by manufacturers.

TECH-64. What percentage of North American-produced passenger cars designed to meet federal or California emission standards will use the following catalytic converter features?

Catalytic Converter Types	Median Response				Interquartile Range			
	To Meet Federal Standards		To Meet California Standards		To Meet Federal Standards		To Meet California Standards	
	2002	2007	2002	2007	2002	2007	2002	2007
Electrically heated	5%	10%	10%	20%	1/5%	5/13%	5/10%	10/20%
Fuel heated	0	0	0	0	0/0	0/0	0/0	0/0
Start-up catalyst with bypass	1	5	5	5	0/5	1/6	1/7	2/10
Start-up catalyst w/o bypass	10	25	20	35	10/15	20/30	16/25	25/40
Metal substrate	10	15	10	20	5/10	10/20	10/20	15/30

Other Responses:

O_2 enrichment – federal standards, 2007: 5%; California standards – 2002: 5%; 2007: 10%

O_2 enrichment membrane – to meet federal standards – 2002: 0%; 2007: 10%

O_2 enrichment membrane – to meet California standards – 2002: 5%; 2007: 15%

New technology systems – to meet federal standards – 2002: 10%; 2007: 20%

New technology systems – to meet California standards – 2002: 10%; 2007: 20%

Selected edited comments

- Federal/California split in 2002 pending NLEV; 2007 federal pending new legislation, assumed similar to California.
- Once somebody demonstrates the capability to meet the standards without supplemental heat/bypass systems, the "benchmarkers" will beat their engineers into line.
- The type of substrate will be driven by cost because the performance of the metal vs. ceramic substrates are now almost the same.

Discussion

Panelists forecast a 20 percent application for both electrically heated catalytic converters and metal substrates and a 35 percent application of start-up catalyst without a bypass by 2007 to meet California emission standards.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was first asked for heated catalysts in the 1994 Delphi VII survey. Start-up catalysts and metal substrates were first addressed in the 1996 Delphi VIII survey. Results for the current survey are compared to past surveys in the following tables.

Catalytic-Converter Features *Federal* Standards						
Forecast for year	**Forecast**	**Electrically heated**	**Fuel heated**	**Start-up catalyst w/bypass**	**Start-up catalyst w/o bypass**	**Metal substrate**
1998	**1994 Delphi VII**	1%	3%	-	-	-
2000	**1996 Delphi VIII**	5	1	5%	10%	10%
2002	**1998 Delphi IX**	5	0	1	10	10
2003	**1994 Delphi VII**	5	10	-	-	-
2005	**1996 Delphi VIII**	10	2	5	25	15
2007	**1998 Delphi IX**	10	0	5	25	15

The current and past surveys are in general agreement, with the exception that the last two surveys suggest a shift from fuel-heated to electrically heated catalytic converters.

Catalytic Converter Features *California* Standards						
Forecast for year	**Forecast**	**Electrically heated**	**Fuel heated**	**Start-up catalyst w/bypass**	**Start-up catalyst w/o bypass**	**Metal substrate**
1998	**1994 Delphi VII**	10	5	-	-	-
2000	**1996 Delphi VIII**	10	5	5	20	10
2002	**1998 Delphi IX**	10	0	5	20	10
2003	**1994 Delphi VII**	20	20	-	-	-
2005	**1996 Delphi VIII**	20	5	5	40	20
2007	**1998 Delphi IX**	20	0	5	35	20

Strategic considerations

In the past three surveys, forecasts have shifted in favor of electrically heated over fuel heated catalytic converters.

Panelists forecast a meaningful application of metal substrates and start-up catalysts without a bypass. One panelist noted that the performance of a ceramic converter is approaching that of a metal substrate converter. In the past metal substrates were used because of superior warm-up characteristics. The choice in the future may be made on cost (not performance), assuming of course that emission standards can be met.

Another panelist's significant comment is that the manufacturer that is able to meet future emission standards without adding auxiliary devices will be at a competitive advantage relative to cost and complexity. This certainly provides a challenge for vehicle manufacturers since many consumers are not concerned with the emission performance of their vehicle.

TECH-65. What percent of North American-produced passenger cars designed to meet federal or California emission standards will incorporate the following emission control devices in 2002 and 2007?

Emission Control Device	Median Response				Interquartile Range			
	Designed to meet federal requirements		Designed to meet California requirements		Designed to meet federal requirements		Designed to meet California requirements	
	2002	2007	2002	2007	2002	2007	2002	2007
Particulate controls	0%	2%	2%	5%	0/1%	0/5%	0/5%	2/10%
Lean NOx trap	1	10	5	15	0/2	5/10	2/5	10/18
Start-up HC trap	2	10	5	15	0/4	5/10	2/10	13/20

Selected edited comments

- California will loosen its laws to allow spark-ignition engines with multimission controls to be sold.
- I consider EGR and converters part of particulate controls.
- I expect less expensive technology than traps through next ten years.
- It is too late to do anything this drastic for 2002.
- New catalyst technologies now under development will mature for 2007.
- NOx trap usage depends on fuel sulfur content.
- Regulation of sulfur content will have a major impact.
- This depends on EPA mandates and legislation.
- We need to meet emission requirements with smarts, not hardware.
- While I believe there will be some sort of lean-NOx conversion system, I would not classify the system as a "NOx trap".

Discussion

Panelists forecast limited use (15 percent or less) of particulate controls, lean NOx traps or start-up HC traps by 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was first asked in the 1996 Delphi VIII survey. The results of the current survey are compared to those of Delphi VIII in the following table.

Emission Control Devices to meet *Federal* Requirements				
Forecast for year →	**2000**	**2002**	**2005**	**2007**
Delphi Forecast →	**Delphi VIII 1996**	**Delphi IX 1998**	**Delphi VIII 1996**	**Delphi IX 1998**
Emission Control Device:				
Particulate controls	1%	0%	3%	2%
Lean NOx trap	1	1	5	10
Start-up HC trap	2	2	5	10

Emission Control Devices to meet *California* Requirements				
Forecast for year →	**2000**	**2002**	**2005**	**2007**
Delphi Forecast →	**Delphi VIII 1996**	**Delphi IX 1998**	**Delphi VIII 1996**	**Delphi IX 1998**
Emission Control Device:				
Particulate controls	2%	2%	5%	5%
Lean NOx trap	5	5	10	15
Start-up HC trap	5	5	10	15

For 2007, panelists in the current survey forecast higher application of lean NOx traps and start-up HC traps to meet federal and California requirements than forecast in Delphi VIII.

Strategic considerations

A comment from one of the panelists likely explains the low-use rate forecast for these devices. That comment is that requirements must be met through "smarts not hardware." Manufacturers are very reluctant to add cost, complexity and weight to a vehicle unless absolutely necessary. Manufacturers apparently believe that, in most cases, more attractive options are available.

It is possible also that these devices are not adequately developed in order to be considered for volume production.

TECH-66 What new components, fuels, fluids or technologies not previously covered in this survey will be introduced in the next decade for North American-produced passenger cars to help meet new emission standards?

Responses:

"Extreme" dependence on software-based solutions to engine problems due to the availability of low-cost microprocessors will require increased availability of software systems engineers and software writers. These are in short supply today.

Adaptive individual cylinder fuel control, fuel quality sensing during cold start, variable accessory loading during cold start and idle, ECM start, electronic throttle control

Alternative to oil lubrication may be tried on limited production. Ceramic bearings, air or electromagnetic (e/m) bearings. Coatings on piston skirts and rings to allow for a reduced fluid film will aid in the reduction of HC emissions due to oil blow-by. Low-wear coating will allow oil seal to last longer. Stiffer blocks and less gasket and seal-sealing surface distortion will increase tightness and reduce leaks.

Clean diesel fuel

Could expect some solar panels for battery charge or accessory lights

Electric brakes

Electronic fuel handling systems—demand system

Evolutionary changes to current fuels

Fuel cell vehicles (4 responses).

Hybrid inertia flywheel-type engine

Hybrid vehicles—gas/electric (3 responses)

I believe the DME made from natural gas as a diesel fuel has one of the greatest potentials as an alternate fuel and should be given more discussion. The oil companies are putting a lot of money into developing fuel cells that can operate on normal gasoline. They have a large network of stations and distribution centers that they would like to retain. Thus, I believe that there is a good chance that gasoline fuel cells will be coming into the market.

Improved fuel-control strategies, fuel composition modifications, improved diesel fuel metering systems, electronic throttle control "drive-by-wire"

Lean-burn engines; in-cylinder pressure sensors; torque sensors

Lightweight MMC connecting rod, ion sensing and ignition control, ultralightweight valves

Lightweight window glazing, composite suspension components (springs, control arm), lightweight speaker that requires low electrical power requirements, no AMP

Low-sulfur gasoline

New catalyst coatings, fast catalyst warm-up strategies, fast engine warm-up strategies

New formula fuel with less of the current organic base (i.e., "era of designer fuels")

New valve trains, lower weight, high specific power engines, CVT and high efficiency transmissions, improved engine management and transmission shift controls, coating technologies, etc.

Newly developed diesel engineering from Europe

Oxygen enrichment (membrane technology) for internal combustion and emissions

Spark control strategies for reduced warm-up times

Supercapacitors, flywheels

Turbocharged, direct-injected diesel engines with four-valves-per-cylinder, "city diesel" of Swedish type with a sulfur content of 0.001%

Use of ultralow-sulfur fuels. Also, a probable small use of diesels with particulate trap technology in the 2007 time frame.

Discussion

A number of new components, fuels, fluids or technologies to meet new emission standards were noted by panelists. Fuel cells and hybrid vehicles received more than one comment.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This comparison is not made for open-ended questions.

Strategic considerations

This is a challenging time for vehicle manufacturers. More stringent emission standards will require development in many areas, including fuels, fuel control, catalyst systems, and electronics. At the same time, alternative power sources such as fuel cells, hybrids, direct-injection spark-ignited engines and advanced diesel engines will vie to replace the current spark-ignited gasoline engine. Vehicle manufacturers must watch developments in all of these areas to remain competitive in the next decade.

There are some very interesting suggestions offered by panelists. They are worth reading carefully. A single panelist may know something that is not common knowledge.

TECH-67. What percentage of North American-produced passenger car engines will incorporate components that are plastic in 2002 and 2007? Please provide your estimate for current vehicles.

	Median Response			Interquartile Response		
Plastic Components	Current Est.	2002	2007	Current Est.	2002	2007
Fuel rails	10%	20%	40%	10/10%	15/25%	30/40%
Intake manifold	15	30	50	10/16	25/36	50/60
Oil pan	2	10	15	1/3	5/10	10/20
Piston skirts	0	0	0	0/0	0/0	0/0
Throttle body	2	10	20	2/4	5/15	13/25
Valve covers	15	30	50	15/15	25/40	40/60

Other Responses:

Timing covers - current: 25%; 2002: 60%; 2007: 75%

Selected edited comments:

- Cost/mass pressures are likely to drive more underhood composite applications as the material demonstrates capability (a few "blips" in the learning curve not withstanding).
- Due to cost and mass, use of composites will continue to grow. Technology development is needed to meet underhood environment requirements.

Discussion

Panelists forecast a significant increase in the use of plastic components for engines in the next decade. By 2007, the following components are forecast to be made of plastic in the percentages shown:

- Fuel rails 40 percent
- Intake manifolds 50 percent
- Oil pans 15 percent
- Throttle body 20 percent
- Valve covers 50 percent

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement with the exception of the current estimate for fuel rails. The mean response for manufacturers is 13 percent, compared to 9 percent for suppliers.

Trend from previous Delphi surveys

Throttle bodies were not covered in a previous Delphi survey. Responses for the other components are in general agreement with past surveys.

Strategic considerations

Panelists forecast greatly expanded use of plastics for engine components in the next decade. Plastic offers the advantages of low weight, the ability to be formed in complex shapes, component consolidation, low cost and protection from corrosion. Also, in applications such as intake manifolds, the smooth inner surfaces are advantageous. However, the issue of recycling may negatively impact the use of plastics in the future. The move to plastics will negatively impact some suppliers as it helps others.

TECH-68. What percentage of spark-ignited engines in North American-produced passenger cars will use these ceramic engine components in 2002 and 2007?

	Median Response		Interquartile Range	
Ceramic Engine Components	**2002**	**2007**	**2002**	**2007**
Exhaust manifold/port liner	2%	10%	0/9%	4/18%
Piston upper ring land	1	5	0/5	0/10
Piston crown	0	5	0/4	0/8
Piston rings, coating	1	5	0/10	0/20
Seals	2	5	0/9	0/15
Turbocharger turbine/rotor (based on % of engines equipped with turbochargers)	10	25	2/25	10/50
Valvetrain components (includes valves, inserts, guide seats, tappets, cam, etc.)	3	5	0/10	1/20
Wrist pins	0	1	0/0	0/5

Selected edited comments

- I assume turbocharger usage will not go above 0.2 percent.
- I would expect a gradual shift favoring select ceramic engine components as initial applications prove successful, manufacturing technology comes along, and costs decrease.
- Water pump seals will continue to utilize ceramics.

Discussion

Panelists forecast that a number of ceramic engine components will have penetrations of 5 to 10 percent by 2007. These include exhaust manifold port liners, piston ring upper lands, piston crowns, piston rings, seals and numerous valvetrain components.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Comparison of forecast: MAT-31

There is a statistically significant difference in mean responses between technology and materials panelists for the ceramic engine components in passenger cars in the years shown in the following table.

Ceramic Engine Components - Percent				
	2002		2007	
	TECH	MAT	TECH	MAT
Piston upper ring land	3.0	0.7	8.0	2.8
Seals	12.4	1.4	16.3	2.8

Technology panelists forecast a higher use of ceramic materials in passenger car engine piston upper ring lands and seals than do materials panelists.

Trend from previous Delphi surveys

Results from the current survey are compared to those of past surveys in the following table. Piston upper ring land and wrist pins were not covered in previous forecasts.

Ceramic Engine Components							
Forecast for year	Forecast	Exhaust manifold/port liner	Piston crown	Piston rings	Seals	Turbocharger turbine/rotor	Valvetrain components
1995	1989 Delphi V	3%	2	0%	2%	5%	2%
	1992 Delphi VI	1	0	0	2	10	2
1998	1994 Delphi VII	1	0	0	5	10	2
2000	1989 Delphi V	10	8	0	10	15	10
	1992 Delphi VI	5	2	5	5	20	10
	1996 Delphi VIII	2	0.	1	2	15	5
2002	1998 Delphi IX	2	0	1	2	10	3
2003	1994 Delphi VII	5	2	2	10	30	10
2005	1996 Delphi VIII	5	5	5	5	28	15
2007	1998 Delphi IX	10	5	5	5	25	5

Results of the current survey are in general agreement with those of previous surveys with the exception of the forecast for valvetrain components. The current forecast of 5 percent is well below the previous two forecasts of 15 percent.

Strategic considerations

Ceramic components are viewed with caution when used inside of an engine. This is because ceramics can be very abrasive when broken into small pieces. This is a concern, even in an exhaust manifold or exhaust port, in that it is possible to ingest material into the combustion chamber from the exhaust during the overlap portion of the cycle. In spite of this concern, panelists forecast a meaningful application of ceramics to engines in the next decade.

Ceramics act as thermal insulators when used in exhaust manifolds or on top of pistons. In the exhaust manifold, insulation increases the temperature of the exhaust gases, thereby promoting more complete burning of hydrocarbons in the manifold or catalytic converter. Warm-up of the converter is also enhanced. Insulation of the piston crown reduces heat flow to the engine, thereby improving thermal efficiency but can result in higher NOx emissions.

The use of ceramics in the piston upper land may allow the top piston ring to be placed closer to the top of the piston. This positioning results in a smaller space above the top piston ring, where unburned hydrocarbons can be trapped during combustion and later exhausted into the exhaust system.

Ceramics in piston rings, seals, turbocharger turbine/rotor, valvetrain components and wrist pins reduce wear and engine friction.

The manufacturability and failure mode of ceramics is a continuing challenge.

TECH-69. Please estimate the mix of transmissions for passenger cars and light trucks manufactured in North America in 2002 and 2007. Total manual plus total automatic should equal 100 percent.

Passenger Cars		Median Response		Interquartile Range	
Transmission	**1996***	**2002**	**2007**	**2002**	**2007**
Manual					
Four-speed	0%	0%	0%	0/0%	0/0%
Five-speed	12.1	11	10	10/13	7/12
Six-speed	0.3	1	1	0/1	0/2
Total manual	12.4				
Automatic					
Three-speed	9.3%	5%	5%	3/7%	0/5%
Four-speed	78.2	79	77	76/81	70/80
Five-speed	0	2	5	0/5	0/10
Continuously variable (CVT)	<1	1	4	0/2	1/6
Total automatic	87.5				
Total	100%				

Light Trucks		Median Response		Interquartile Range	
Transmission	**1996***	**2002**	**2007**	**2002**	**2007**
Manual					
Four-speed	0%	0%	0%	0/0%	0/0%
Five-speed	17.5	17	15	15/18	13/18
Six-speed	0	0	0	0/1	0/2
Total manual	17.5				
Automatic					
Three-speed	5.6%	4%	0%	0/5%	0/4%
Four-speed	76.9	77	77	73/80	70/80
Five-speed	0	0	2	0/5	0/10
Continuously variable (CVT)	0	0	0	0/0	0/3
Total automatic	82.5				
Total	100%				

* **Source:** Ward's Automotive Reports, Feb. 17 and Mar. 3, 1997.

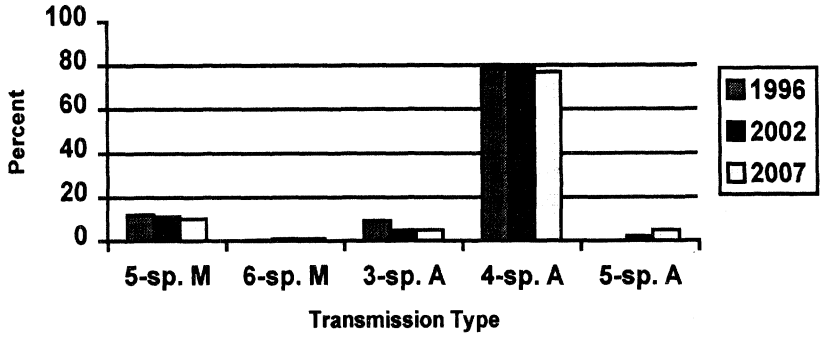
Selected edited comments

- CVT usage will be fuel economy demand driven rather than technology-limited by 2007.
- There will be a gradual shift to more five-speed automatics and CVTs consistent with increasing fuel economy/CAFE pressures.
- This depends greatly on pricing policies.

Discussion

Panelists forecast that most (70-75 percent) transmissions for passenger cars and light trucks will continue to be four-speed automatics. Panelists also forecast five-speed automatic transmission use of 5 percent and 2 percent for passenger cars and light trucks, respectively, by 2007. A 4 percent use of CVT (continuously variable transmissions) is forecast for passenger cars in that same time frame. Three-speed automatic transmission use is forecast to decrease from 9.3 percent currently to 5 percent in 2007 for passenger cars and from 5.6 percent to zero percent in light trucks.

Transmission Forecast - Passenger cars



Manufacturer/supplier comparison

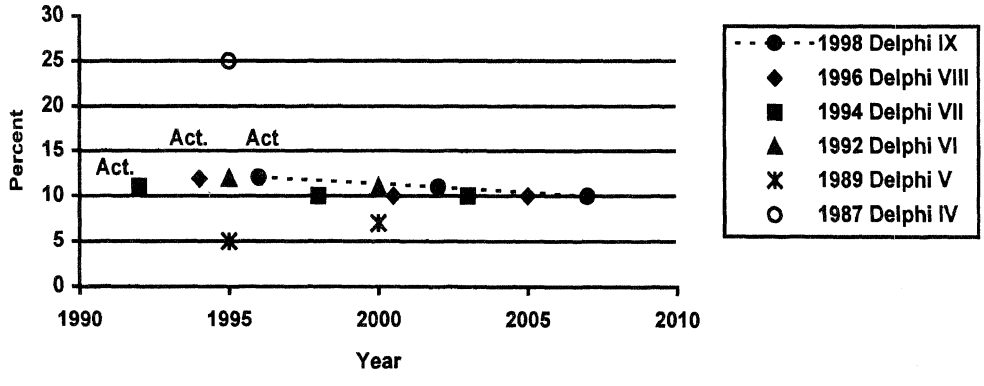
There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

Passenger cars:

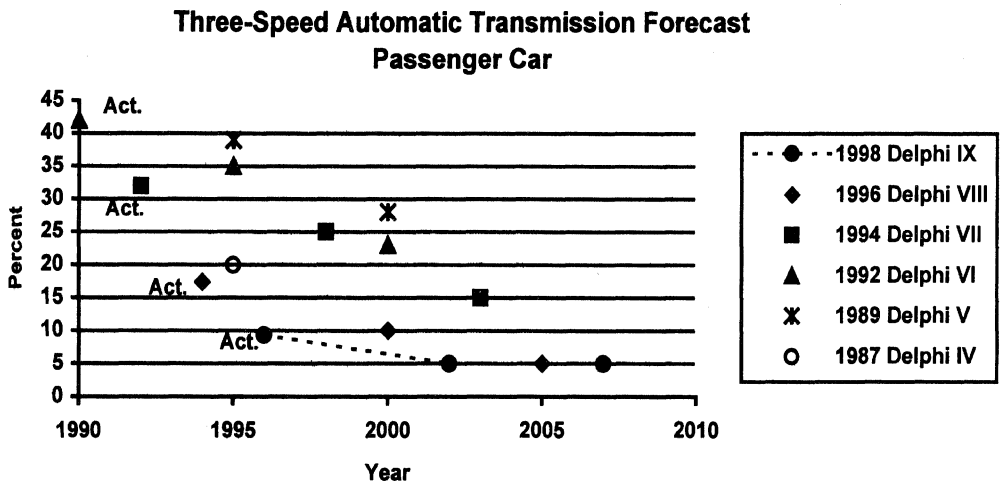
The results of the current survey for five-speed manual transmissions are compared to those of past surveys in the following graph.

Five-Speed Manual Transmission Forecast
Passenger Car



Results of the current forecast are similar to those of the past three forecasts. There is

considerable variance from results of earlier forecasts 1989 Delphi V and 1987 Delphi IV, however.



The current forecast for three-speed automatic transmissions in passenger cars is below those of previous forecasts.

Light trucks:

Light trucks were not included in forecasts prior to 1996 Delphi VIII. The results of the current survey are compared to those of the 1996 Delphi VIII survey in the following table.

Light Truck Transmissions						
		Manual		Automatic		
Forecast for year	Forecast	Four-speed	Five-speed	Three-speed	Four-speed	Five-speed
1994 Act.	1996 Delphi VIII	0%	21.6%	5.5%	72.9%	0%
1996 Act.	1998 Delphi IX	0	17.5	5.6	76.9	0
2000	1996 Delphi VIII	11	7	3	75	0
2002	1998 Delphi IX	0	17	4	77	0
2005	1996 Delphi VIII	10	10	0	75	4
2007	1998 Delphi IX	0	15	0	77	2

The two surveys are in agreement for automatic transmissions. For manual transmissions, the current survey forecasts no application of four-speed transmissions, whereas Delphi VIII forecast 10 percent by 2005. Similarly, the current survey forecasts little change in five-speed manuals, whereas Delphi VIII panelists forecast a significant decrease in their use.

Strategic considerations

Increasing the number of transmission-forward speeds is one of the tools that manufacturers have to improve fuel economy and performance. Panelists forecast a modest trend in that direction for both passenger cars and light trucks. This trend will be greatly influenced by fuel price and

availability and legislation related to fuel economy. Increased cost will make manufacturers wary of making this move unnecessarily, however.

In passenger cars, the move from three-speed automatic transmissions to four-speeds has proceeded at a rate much faster than forecast by previous Delphi surveys. This move has been driven by the need for increased fuel economy for CAFE as well as competitive requirements.

Some application of continuously variable transmissions (CVT) is forecast by 2007 for passenger cars. Forecast increasing fuel economy requirements are the driving force behind this move. Some impressive developments in CVT technology appear to be on the horizon that could have a significant impact on their use.

The increased cost of the greater number of forward speeds will be partially recovered by the consumer through improved fuel economy.

Automatic transmissions continue to dominate, and little change in the manual/automatic transmission mix is forecast.

TECH-70. Chrysler, BMW and Honda have introduced sequential-shift automatic transmissions that can be selectively shifted similar to a manual transmission. Some literature has discussed future automatic transmissions without torque converters and manual transmissions without clutches. Please forecast the percent of passenger cars produced in North America that will incorporate each of these features by 2002 and 2007.

Transmission Feature	Median Response		Interquartile Range	
	2002	2007	2002	2007
Sequential-shift automatic transmissions	5%	5%	2/5%	3/10%
Automatic transmission w/o torque converter	2	5	0/5	2/10
Manual transmission without clutch	1	2	0/2	1/5

Selected edited comments

- Sequential shift automatics will likely become standard on sporty image vehicles and penetration will follow that vehicle segment penetration. Automatic clutch manuals and manuals with full automation which function as automatics have a significant fuel economy benefit at the trade-off of smoothness. Penetration will depend on market need for fuel economy improvement.
- This question is more appropriate for passenger cars produced in areas other than North America.

Discussion

Panelists forecast limited application (5 percent or less) in passenger cars of sequential-shift automatic transmissions, automatic transmissions without torque converters, and manual transmissions without a clutch by 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Strategic considerations

Sequential-shift automatic transmissions provide the driving convenience of an automatic transmission, with some of the driver feel of a manual transmission. As noted in the comments, this feature is likely to be used on sporty image vehicles.

Also as noted in the comments, automatic-shifting manual transmissions may be used to provide the convenience of an automatic transmission and the fuel economy of a manual transmission. The efficiency of automatic transmissions has improved considerably since the introduction of the locking converter. Nonetheless, the torque converter of an automatic transmission reduces efficiency during unlocked modes of driving such as acceleration.

These devices may be widely used if fuel prices increase substantially or more rigid fuel economy standards are enacted.

With the current forecast for fuel prices and legislated fuel economy standards, panelists forecast relatively low application of these devices.

TECH-71. What percentage of North American-produced passenger cars will use the following drivetrain configurations in 2002 and 2007?

		Median Response		Interquartile Range	
Drivetrain Configuration	**1996***	**2002**	**2007**	**2002**	**2007**
Front engine, front drive	87.8%	90%	90%	88/90%	87/93%
Front engine, rear drive	10.9	9	6	8/10	5/8
Front engine, four-wheel or all-wheel drive	1.3	2	3	1/3	1/5
Total	100%				

***Source:** Ward's Automotive Reports, Feb. 3, 1997 and OSAT estimates.

Selected edited comments

- A substantial increase in front engine, four-wheel or all-wheel drive is projected in SUV/minivan categories.
- I expect rear wheel drive to stage a modest "comeback," aided by traction control in snowbelt regions.
- The only cars to remain rear-wheel drive will be high performance exotics, muscle cars and some luxury European sedans.
- The trend will continue slowly toward front-wheel drive with only high-performance vehicles and some high-end luxury sedans remaining rear-wheel drive.

Discussion

Panelists forecast that front engine, front drive will remain the dominant drivetrain configuration through 2007 and will be used in 90 percent of passenger cars in that time frame.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

Results of the current survey are compared to those of earlier surveys in the following table.

Drivetrain Configuration Forecasts				
Forecast for year	**Forecast**	**Front engine Front drive**	**Front engine Rear drive**	**Front engine 4-wheel drive**
1994 Est.	**1996 Delphi VIII**	89.6%	10%	0.4%
1995	**1987 Delphi IV**	76	17	5
	1989 Delphi V	79	18	3
	1992 Delphi VI	88	11	1
1996 Est.	**1998 Delphi IX**	87.8	10.9	1.3
1998	**1994 Delphi VII**	88	10	1
2000	**1989 Delphi V**	80	15	5
	1992 Delphi VI	87	10	3
	1996 Delphi VIII	90	9	0.7
2002	**1998 Delphi IX**	90	9	2
2003	**1994 Delphi VII**	89	9.9	1
2005	**1996 Delphi VIII**	92	6	1
2007	**1998 Delphi IX**	90	6	3

The results of the current survey are in general agreement with previous surveys with the exception of forecasts for 1995. In Delphi IV and Delphi V front engine/rear drive was forecast at 17 and 18 percent respectively for 1995, in contrast to an actual penetration of 10 percent. Delphi IV and Delphi V panelists forecast lower penetration of front engine/front drive.

Strategic considerations

Front engine/front drive is forecast to remain the dominant drivetrain configuration through 2007. This configuration provides improved fuel economy as a result of reduced vehicle weight and drivetrain losses. Traction on wet or icy surfaces is also significantly better than with rear wheel drive. Furthermore, interior packaging space is optimized as a result of the absence of a driveshaft.

Rear drive will continue to be used in high-performance vehicles. In this application, performance is enhanced on dry road surfaces because of weight transfer to the rear wheels during rapid acceleration. Rear drive also offers enhanced trailer towing capability as a result of increased weight on the rear wheels. In the past, rear-drive transmissions have also had superior load carrying capability. The application of traction control to rear-drive vehicles has significantly improved traction in wet or icy conditions.

Four-wheel or all-wheel drive is forecast to remain in only a small number of passenger cars. This is likely because this configuration is not generally available in passenger cars offered by domestic manufacturers. Customers desiring four-wheel or all-wheel drive are currently purchasing sport utility vehicles or passenger cars made by foreign manufacturers.

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TECH-72a. For a typical midsized passenger car, what percentage of total vehicle cost of North American-produced passenger cars is attributed to electrical and electronic systems currently and will be in 2002 and 2007? Include motors, wires, electronics and all other electrical components.

b. What percentage of total vehicle cost will be attributed only to electronic components?

	Median Response			Interquartile Range		
Vehicle Electrical/Electronic Cost as Percent of Total Vehicle Cost	**Current Est.**	**2002**	**2007**	**Current Est.**	**2002**	**2007**
a. Total combined electrical and electronic cost	20%	22%	24%	12/25%	15/30%	18/35%
b. Total electronic cost	13	15	19	7/18	10/25	12/30
Electronic Component Classes:						
Semiconductors/microprocessors (active devices)	6	7	8	5/10	5/12	5/15
Sensors (e.g., wheel speed, throttle position)	2	4	5	2/5	2/7	2/8
Actuators ("smart actuators" - does not include traditional electric-powered devices like power seats or blowers)	2	3	5	1/4	2/5	3/8

Selected edited comments

- Increases in electronics utilization will be offset by lower cost.
- Increasing electrical/electronic content will be partially offset by decreasing costs for the electronic (vs. electrical) components.
- Sensor cost will decrease, but more sensors will be used; IC/MP will reduce in cost.

Discussion

Panelists forecast that the combined cost of electrical and electronic content in a vehicle will increase to 24 percent of the total cost of a vehicle by 2007, compared to 20 percent currently.

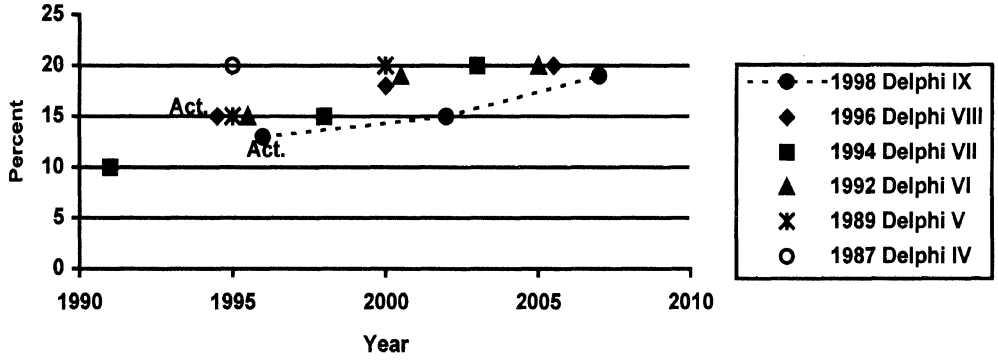
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

In previous Delphi forecasts, this question was asked only for electronic content. The results of the current survey for electronic content are compared to those of previous surveys in the following graph.

Electronics as Percentage of Total Vehicle Costs Forecast
North American Passenger Car Production



Results of the current forecast are below those of previous forecasts.

Strategic considerations

The cost of electrical and electronics as a percentage of total vehicle cost is forecast to increase in the next decade. This increase is in spite of the fact that the cost of electronic components is expected to decrease. This would indicate that total electronic content will increase at a rate greater than the total cost increase.

Electronic content is expected to increase in areas of airbag controls, engine and transmission controls and the addition of electronic features.

In many respects, automotive electronics is maturing, but in others the revolution continues. One important trend is the blending of automotive and consumer electronics technology. Cost reduction is facilitated by this trend.

Most new features that are being considered for the future will heavily depend on electronics as an enabling technology.

TECH-73. What percentage of North American-produced passenger cars will utilize at least one multiplexed (MPX) power subsystem by 2002 and 2007? Please estimate for current vehicles.

	Median Response			Interquartile Range		
Passenger Car	Current Est.	2002	2007	Current Est.	2002	2007
Multiplexed power subsystem utilization	3%	10%	23%	1/5%	4/25%	10/49%

Discussion

Panelists forecast that multiplexed power subsystems will be used on 23 percent of passenger cars in 2007 compared to 3 percent currently.

Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers for the areas shown in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

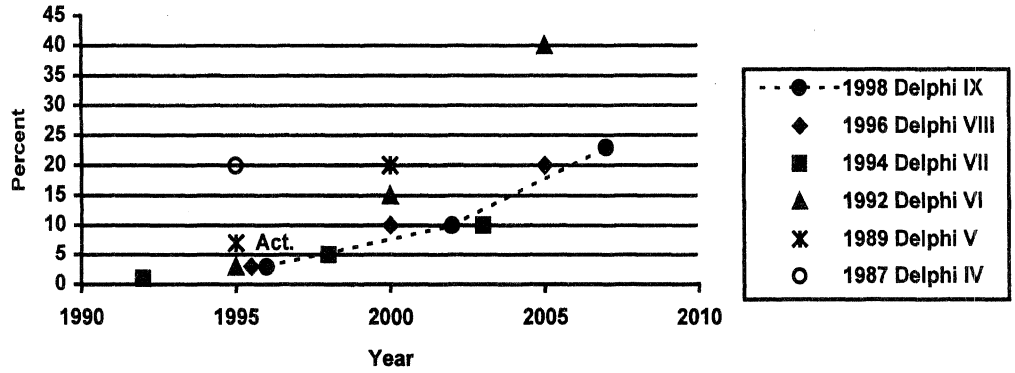
Passenger Car Multiplexed Power Subsystems			
Current Mean		2002 Mean	
Mfr.	Supp.	Mfr.	Supp.
7%	2%	19%	10%

Manufacturers forecast higher use of multiplexed power subsystems than suppliers.

Trend from previous Delphi surveys

Results of the current survey are compared to those of past surveys in the following graph.

Multiplexed Power Sub-System Forecasts North American Passenger Car Production



The current survey is in agreement with the previous two surveys, but forecasts significantly lower penetration than earlier surveys. The current actual penetration is also well below the forecasts for this time frame in the 1987 survey (Delphi IV).

Strategic considerations

This technology has not progressed at the rate forecast in earlier surveys. This is not an unusual occurrence in the application of new vehicle technology. Possible explanations for this may be that current technology is a moving target or that there are problems in the development of a new technology. Still, significant growth is forecast from today's level.

For multiplexing, cost of interfaces and validation of reliability appear to be factors limiting widespread use in today's vehicles.

The incentives for development of this technology are weight reduction, reduced space requirements, diagnostic potential and, possibly, reduced cost and better reliability.

TECH-74. What percentage of multiplexed systems will utilize a fiber optic control bus technique rather than wire control bus by 2007?

	Median Response	Interquartile Range
	2007	2007
Multiplexed systems fiber optics	10	2/21

Selected edited comments

- Telecommunications has shown fiberoptics is possible but MPX must be demonstrated first on traditional systems according to minimized risk strategy.
- There is a high cost; we need to fully exploit wire multiplexing.

Discussion

Panelists forecast that 10 percent of multiplexed systems will utilize a fiber optic control bus technique by 2007.

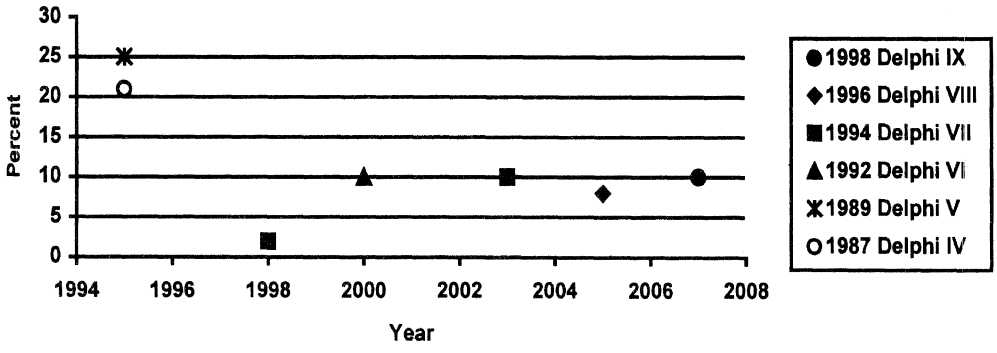
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

Results of the current survey are compared to those of previous surveys in the following graph.

Multiplexed Systems Utilizing Fiber Optics Forecasts



The current survey is in agreement with the previous three surveys, but forecasts significantly lower penetration than the earlier surveys, Delphi IV and Delphi V.

Strategic considerations

Like multiplexing, the application of fiber-optic control has not proceeded at a rate forecast by earlier surveys. Panelists note in their comments that high cost and validation are limiting factors. Weight reduction and elimination of electromagnetic interference are incentives for use of this technology. In spite of these limitations, panelists forecast that application will begin by 2007.

TECH-75. What percentage of North American-produced passenger cars will employ the following electronic/electrical features as factory-installed equipment in 2002 and 2007?

		Median Response		Interquartile Range	
Electronic/Electrical Features	**1996***	**2002**	**2007**	**2002**	**2007**
Antitheft ('95 MY)	29.5%	40%	50%	35/50%	40/70%
Brake by wire	0	1	5	0/5	2/10
CD player	14.5	25	40	20/30	25/50
Cellular phones	0.4	5	10	1/10	5/25
Cruise control	77.1	80	85	80/80	80/90
Digital audio tape (DAT)	0	1	5	0/5	0/15
Drive-by-wire (electronic throttle control)	0	4	10	1/10	5/25
Electrochromatic glass	0	1	4	0/3	2/10
Electronic keyless entry ('95 MY)	32.7	40	60	40/50	50/70
Electrorheological fluids	0	0	1	0/1	0/5
Onboard diagnostic via expert systems (AI)	0	2	8	0/10	5/20
Voice-activated/interactive controls	0	1	4	0/5	1/10

* **Source:** Ward's Automotive Reports, Feb. 17, 1997; Automotive News Market Data, Aug., 1996; and OSAT estimates.

Selected edited comments

- Most cell phones will be installed by buyers.

Discussion

Panelists forecast that the application of many electrical/electronic features such as factory-installed equipment will significantly increase by 2007.

Manufacturer/supplier comparison

Responses for manufacturers and suppliers are statistically significantly different for the areas noted in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference, and are compared in this analysis.

Passenger Car Electronic/electrical Features				
	2002 Mean		2007 Mean	
Feature	**Mfr.**	**Supp.**	**Mfr.**	**Supp.**
Antitheft	-	-	61%	52%
Drive-by-wire	9	4	22	11
Onboard diagnostic via expert systems	8	3	-	-

Manufacturers forecast higher application rates than suppliers for the items having a statistically significant difference in responses.

Trend from previous Delphi surveys

Brake-by-wire, electrochromic glass and electrorheological fluids were not covered in a previous survey.

Results of the current survey are similar to those of previous surveys except as follows:

Antitheft: The current actual penetration and forecasts for 2002 and 2007 are greater than previous forecasts. The actual penetration for 1993 from 1996 Delphi VIII was only 9.8 percent. (See chart in Strategic considerations that follow.)

CD player: The current forecast for 2002 and 2007 is for greater application than previous forecasts.

Cellular phones: The 1992 Delphi VI forecast of 25 percent for 2000 was much greater than any subsequent forecasts.

Electronic keyless entry: The current forecast is for greater application than previous forecasts. The actual application rate for 1996 of 32.7 percent is a significant increase from the 1993 actual penetration of 16.3 percent. (See chart in Strategic considerations that follow.)

Onboard diagnostic via expert systems-AI: The 1992 Delphi VI forecast of 15 percent for 2000 was much greater than any subsequent forecasts.

Strategic considerations

The application of some electronic components and features has increased significantly in the last few years. The baseline actual penetrations for some of these systems (for 1996) from the current survey are compared to the 1994 actual penetrations of the previous survey (1996 Delphi VIII) in the following table.

Electronic Features	Delphi VIII 1994 Est.	Delphi IX 1996 Est.
Antitheft	9.8%	29.5%
CD player	3.8	14.5
Cellular phones	0.1	.4
Electronic keyless entry	16.3	32.7

The electronic systems noted have increased in volume by factors of two to four, although in the case of cellular phones, the volume remains low.

The increased volume of electronic components installed by manufacturers provides opportunities for both manufacturers and suppliers. Panelists forecast that this increase in volume will continue for the next decade.

In the case of CD players, in some instances these systems replace cassette tape decks rather than add a new feature. However, both tape decks and CD players are installed on many vehicles.

The factory installation of cellular telephones has not met forecasts from earlier Delphi surveys. This feature continues to be primarily an after-market system. It is a challenge to manufacturers to develop innovative methods of marketing this widely used feature in production vehicles. Perhaps a mutual agreement with a cellular carrier would be of advantage to both vehicle manufacturers and the cellular carrier.

Affordability has often been noted as a restraining factor in the application of new features. It appears that customers are willing and able to pay for the new features noted above. Clearly, the key to success of any feature is winning the price/value trade-off with the customers.

TECH-76. What percentage of passenger cars produced in North America will utilize the following systems voltages by 2007?

Voltage level	Median 2007	Interquartile Range 2007
24V	1%	0/10%
36V	0	0/0
48V	0	0/0
12/24V	6	1/20
12/36V	0	0/2
12/48V	0	0/5

Selected edited comments

- 12 VDC will remain king.
- I don't see a compelling case to challenge the existing 12-volt infrastructure. If/when such a case develops, dual voltage systems will enable the transition.
- Electric brakes will drive multivoltage systems.
- The majority of vehicles will probably be 12VDC.
- This will take a long time to phase in because most products will need to be retooled to be compatible with higher voltages.
- We would devise a higher voltage system or a dual voltage system, but the exact voltages and roll-out timing is TBD.

Discussion

Panelists forecast that 12-volt electrical systems will continue to be used on most vehicles in the next decade. They forecast, however, that a combined 12/24-volt system will be found in 6 percent of vehicles in 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was first asked in this form in the 1994 Delphi VII survey. The results of the current survey are compared to those of the past two surveys in the following table. Voltages not included received median responses of zero in all surveys.

For year →	2003	2005	2007
Systems Voltages	Delphi VII 1994	Delphi VIII 1994 Est.	Delphi IX 1996 Est.
24V	0%	5%	1%
12/24V	0	10	6

There is consensus between the current survey and Delphi VIII that there will be some application of 24V or 12/24V systems in the next decade. The number of these systems in that time frame is not clear, however.

Strategic considerations

The driving forces behind the consideration of higher system voltages are the increasing number of electric systems and components and the need to improve the efficiency of vehicle systems for fuel economy.

As electrical systems are added or expanded, there is an increasing need for larger alternators and wires. This causes packaging problems and increases vehicle weight. By moving to a higher voltage system, alternator and wire sizes can be reduced.

The move to higher voltage systems will be difficult and will require considerable planning. All electrical systems are currently designed to run on 12 volts. These systems cannot be changed in a short period of time from financial, engineering, and manufacturing perspectives. It is likely that dual-voltage systems will be used initially and perhaps even in the long term, in order to allow some systems to run at higher voltages and keep lighting (for example) running on lower voltage.

TECH-77 How many rotating and linear electric motors will typical standard (i.e., compact, midsized) and luxury North American-produced passenger cars have in 2002 and 2007? Include door locks, mirrors, and trunk lid actuators.

Please refer to the examples provided on the following page to assist you in your thinking as you make your estimates.

	Median Response			Interquartile Range		
Passenger Cars Having Rotating and Linear Electric Motors	**Current Est.**	**2002**	**2007**	**Current Est.**	**2002**	**2007**
Standard (include compact, midsized) < $25,000	30	31	40	25/30	30/40	30/50
Luxury > $25,000	50	60	65	40/50	50/60	55/75

Selected edited comments

- Add and delete applications at little net change.
- Cost/mass pressures will help constrain the marketing "content-creep" phenomenon.
- Motor growth will continue in areas of power steering assist and brake-by-wire in the luxury models. Standard cars will catch up with the luxury models due to consumers' desires.
- Standard will continue to hold down cost by minimizing "features."
- Your segments are very broad. What is typically considered a luxury car is at least $35,000. Midsize cars are usually in the $25,000 range.

Electric Motor Content
Mercedes S600, Cadillac STS, Neon

Electric Motor Function	1995 MY Mercedes S600	1995 MY Cadillac STS	1995 MY Loaded Neon
Headlamp wiper	2	-	-
Headlamp washer	1	-	-
Cooling fan	1	1	1
Wiper motor	1	1	1
Washer pump	1	1	1
Cluster gauge indicators	6	3	2
ABS system	1	1	1
Active shocks/damper (ride control)	4	4	-
Climate control damper/system	6	6	4
A/C blower	2	1	1
Mirrors outside	6	4	4
Sun roof	1	1	1
Power seat (driver/passenger)	14	10	-
Power headrest rear seat	1	-	-
Power door locks	4	4	4
Power windows (antipinch)	4	4	4
Radio/tape player	1	1	1
CD player	1	1	1
Rear sun screen	1	-	-
In-tank fuel pump	1	1	-
Power antenna	1	1	-
Power rear parking guides	2	-	-
Deck lid pull down	1	1	-
Power operated deck lid handle	1	-	-
Throttle by wire	1	-	-
Seat belt presenter	2	-	-
Power steering column tilt/pos.	2	-	-
Suspension leveling pump (air shocks)	1	1	-
Total	70 Motors	47 Motors	25 Motors

Source: Joseph F. Ziomek, JFZ & Associates, Feb. 5, 1995, submitted as a comment.

Other Responses:

Headlamp Leveling	2
New Motor Uses	
Power Door Opener	2
Twin Rear Power Seats (BMW)	8
Total New	**12**

Discussion

Panelists forecast that the number of rotating and linear motors will increase to 40 by 2007 on a standard passenger car, compared to 30 currently. On luxury vehicles, this number is forecast to increase to 65 from 50 currently.

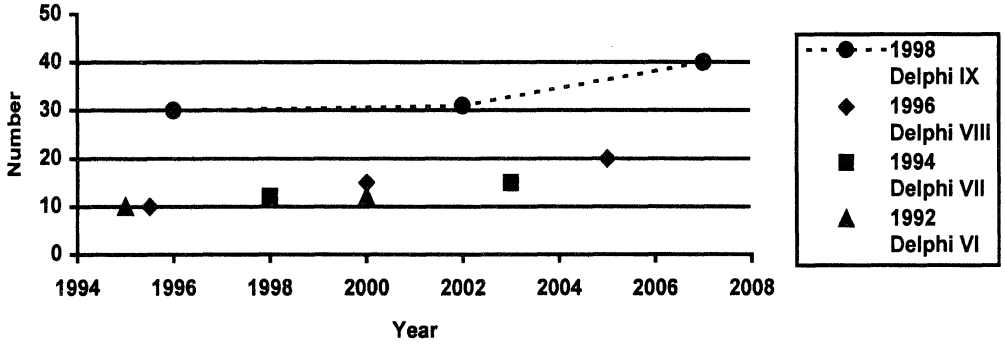
Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

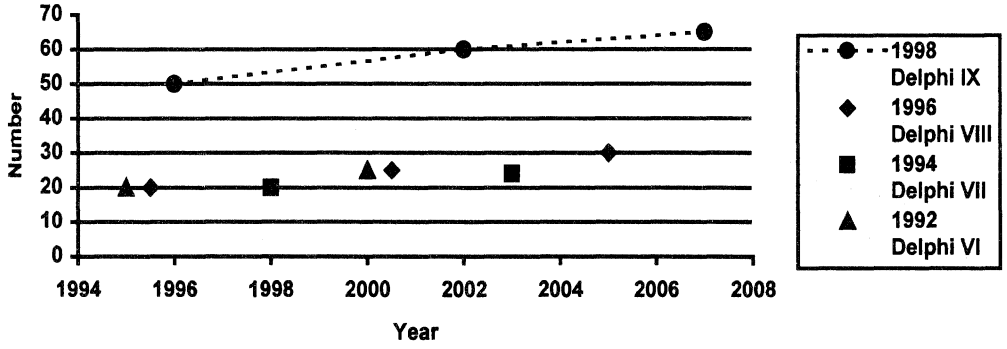
Trend from previous Delphi surveys

Results of the current survey are compared to those of past surveys in the following graphs.

Standard Vehicle Electric Motors Forecasts



Luxury Vehicle Electric Motors Forecasts



The number of electric motors estimated currently and forecast for the future are significantly higher in the current survey than previous surveys. It is not clear whether this is due to an actual increase in the number of motors since the last survey, or if it is a result of a different, more comprehensive, count for the current estimate. The motor count supplied by JFZ Associates is in quite good agreement with the panelists' median estimate.

Strategic considerations

The forecast for an increase in the number of electric motors used in passenger vehicles creates a number of challenges for vehicle manufacturers. First, as noted in TECH-76, alternator size is currently limited by packaging cost, weight, and fuel economy constraints. Also, the increased number of motors and the features that they support will add weight to the vehicle, contrary to the desire to reduce weight for improved fuel economy.

On the other hand, increased electric motor sales means higher sales of high-profit options for manufacturers. This forecast is also good news for motor suppliers and adjunct componentry suppliers.

TECH-78. What percentage of North American-produced passenger cars powered by gasoline engines will be equipped with these electric motor-driven devices by 2002 and 2007? Please provide your estimates for current vehicles.

	Median Response			Interquartile Range		
Electric Motor-Driven	Current Estimate	2002	2007	Current Estimate	2002	2007
A/C compressor	0%	2%	6%	0/2%	0/10%	1/17%
Air pump	1	9	10	0/5	1/20	2/26
Power brakes	0	2	10	0/1	1/10	2/20
Power steering pump	1	5	10	0/2	2/10	5/20
Water pump	0	1	2	0/0	0/5	0/10

Selected edited comments

- Brakes may be the focus—thus, an integration with ABS.
- I do not believe conversion efficiencies will permit electric drives. The only driver is the lowering of hoods which could force accessories off the belts.
- I don't know current percentages, but emission requirements will force high usage of air pumps, and the majority will be electric.

Discussion

Electric motor-driven air pumps, power brakes and power steering pumps are forecast to have penetrations of 10 percent by 2007. Electric motor-driven A/C compressors are forecast at 6 percent in the same time frame.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of responses for air pumps. Responses for manufacturers and suppliers are compared in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

Electric Motor-Driven Air Pump			
2002		2007	
Mfr.	Supp.	Mfr.	Supp.
23%	7%	33%	10%

Manufacturers forecast higher use of electrically driven air pumps than suppliers.

Trend from previous Delphi surveys

Results from the current survey are compared to those of previous surveys in the following table.

Electric Motor-Driven Devices Forecasts									
For the year →	1995	1996	1998	2000		2002	2003	2005	2007
Motor Driven Device	Delphi VI 1992	Delphi IX 1998	Delphi VII 1994	Delphi VI 1992	Delphi VIII 1996	Delphi IX 1998	Delphi VII 1994	Delphi VIII 1996	Delphi IX 1998
A/C compressor	0%	0%	0%	5%	1%	2%	5%	3%	6%
Air pump	3	1	3	10	5	9	5	10	10
Power brakes	-	0	0	-	2	2	5	5	10
Power steering pump	-	1	1	-	2	5	5	10	10
Water pump	0.5	0	0	3	0	1	3	1	2

Results of the current survey are in general agreement, with the exception of the 2007 forecast for power brakes. The current survey forecasted a higher penetration for electric power brakes for 2007 than previous surveys.

Strategic considerations

Advantages for electric motor-driven accessories are ease of packaging and the potential for improved fuel economy as a result of running the motor only when it is required.

As noted in TECH-76, increasing electric-load requirements may require an increase in the size of the alternator. This can create packaging problems in many vehicle applications. Load management may reduce the impact of this requirement.

TECH-79. What percentage of North American-produced passenger cars will utilize noise cancellation technologies by 2002 and 2007?

	Median Response		Interquartile Range	
Technologies	**2002**	**2007**	**2002**	**2007**
Electronic interior noise cancellation				
Digital signal processing (DSP) systems integrated into audio systems	2%	5%	1/5%	2/15%
Electronic exhaust noise cancellation				
"Electronic" muffler	1	3	0/5	1/14

Selected edited comments

- I also expect some use for intake systems.
- The energy needed to make the electronic muffler is still a major technical and economic issue.
- These technologies are too costly for the benefit.

Discussion

Electronic interior and exhaust noise-cancellation technologies are forecast for 5 percent or less of passenger cars by 2007.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of responses for electronic interior noise cancellation for 2002. For this item, manufacturers forecast 8 percent versus 3 percent for suppliers. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

Trend from previous Delphi surveys

This question was first asked in the 1992 survey, Delphi VI. A comparison of the current survey to previous surveys is shown in the following table.

Electronic Noise Cancellation Forecast							
For the year →	**1998**	**2000**		**2002**	**2003**	**2005**	**2007**
	Delphi VII	**Delphi VI**	**Delphi VIII**	**Delphi IX**	**Delphi VII**	**Delphi VIII**	**Delphi IX**
Technology	**1994**	**1992**	**1996**	**1998**	**1994**	**1996**	**1998**
Electronic interior noise Cancellation	1%	10%	1%	2%	5%	5%	5%
Electronic Exhaust Noise Cancellation	1	10	1	1	5	4	3%

Results of the current survey are in general agreement with past surveys with the exception of the 1992 Delphi VI survey. The forecast of 10 percent for both interior and exhaust noise cancellation in that survey is considerably higher than subsequent forecasts.

Strategic considerations

Cost is the limiting factor in the application of noise-cancellation technology. One panelist noted that energy requirements are also a challenge. Advantages include reduced noise, and potentially weight, by eliminating sound-reducing materials.

Electronic exhaust noise cancellation offers the potential for improved performance by reducing exhaust back pressure in the muffler.

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TECH-80. What new technologies that have not been previously covered in the questionnaire are likely to emerge in the next decade that will have significant impact on the following passenger car and light truck vehicle systems?

Responses:

Body Exterior

Dent-resistant or self-mending plastics

Hang-on plastic/aluminum body panels like the '65 Corvette

Hardcoated plastic components for UV protection

Magnesium high-surface-area components

More composite type material from aircraft industry

Scratch-resistant and peck-resistant coatings

Simplified body structure—spaceframe

Ultrasonic welding of panels to give seamless appearance

Body Interior

Additional applications of airbags and passive safety

All belts to seat (rationale, approaches)

Ergonomic design

Ergonomics designed for the aging driver

Extensive use of high-strength lightweight seat design and use of light weight materials

Flat panel "instrument cluster"

High solar durability interiors requiring urethanes, TPO skins; pending legislation to prohibit PVC use, particularly in Europe; added emphasis on cockpit I.P. build

Integrated systems (interior pods) to be supplied by large tier one suppliers

Occupant position sensing for control of safety and comfort systems

Sound systems to reduce weight and improve fuel economy, also air filtration

Chassis

Aluminum and metal matrix composites (mmc) everywhere

Composite plastic components

Electric power steering

Electronic shock control

Integrated steering/suspension controls/vehicle dynamics

Magnesium components; brakes: new lightweight materials

Micromachined sensors for chassis control (stability)

Multilink suspensions

Use of fine-tuned chassis designs using aluminum and high-strength steels

Yaw control as a no-cost option along with intelligent cruise control (ICC)

Comfort/convenience

Adaptive seat cushions for firmer support for wider body ranges

Computer in-car, phone system to "call" car, information display

GPS-based comfort systems (i.e., GPS knows where you are and alters the C/C systems to match)

Heat (and cool) storage systems to maintain comfortable temperature at start

Increased information, communication systems

Instant comfort

Navigation systems, A/C compressor cut-out during accels, heated seats

Electrical

12/36V, starter/generator

3V ICs

Flat, flexible, high-resistance tape with embedded "small" diameter wire

Flexible interconnect (i.e., flexible circuits and flat flexible cable) will continue to grow in use for modular systems (i.e., door panels, instrument panels, headliners) and engine controller units/sensors.

Head-up displays, navigation systems, active cruise control, advanced collision avoidance systems

Load management/higher power capability; new headlight technology (i.e., HID, fluorescent, fiber optic)

Many more electric controls—especially for sensors and diagnostics for preventive maintenance

Modularized electrical systems, easy to diagnose and replace

MPX with a Gateway (ITS based) to allow upfitting and upgrading of used cars to a newer functional level

Multispeed accessory belt drives, drive-by-wire

Power electronic building blocks (PEBBS)

Push to reduce electrical loads

Engine

Adiabatic technology; more flexible fuels

Compacted graphite iron (CGI) for diesel engine blocks

Diesel engines with modified/engineered fuel

Electronic software engine management—the end of precalibrated functions

End-to-end engines—flat two-stroke lighter in weight

Gas turbine engines, fuel cells, flywheels, super capacitors

Heat management system

Hybrid flywheel inertia-based engines

Hybrid vehicles (4 responses)

Low-mass reciprocating components, hollow, crankshafts, ionization, spark control, coolant control, fuel-cell technology, dry sump oil system, fuel-cell technology 2020+

Modularization with interchangeable components

More extensive diesel applications, better lubricants, valvetrain modules

Nonelectromagnetic programmable valvetrain systems

The (direct injection) diesel could re-emerge as a serious CAFE-driven powertrain by 2007

Turbine

Variable cam phasors

Variable compression ratio, variable displacement

Glass

Hard-coated plastic (3 responses)

IR/UV reflective glass, Lexan

Lower mass alternatives: laminates, acrylics, etc. (4 responses)

More solar glass and laminated side glass

Thicker for sound reduction

Other

Accessory performance—especially efficiency of A/C compressor and alternator

Crossover vehicles will "muddy" the car/truck continuum; does anyone/everyone expect the market diversions from cars to trucks to continue/accelerate/slow down?

Higher quality

More software-driven systems

Weight reductions

Safety

Adjustable pedal passenger cars and light trucks

Airbags for pedestrian safety

Antidrowsiness/alertness systems

Brake-failure warning

Broader test considerations relative to moderate crash cost-to-repair/insurance rates

Different types of "smart" airbags, aluminum brake rotors, electronic yaw control

I/R night vision, drunk- and drowsy-driver detection

Mass GPS control of vehicle position for navigation and collision avoidance, automated highways

More airbags that are programmable based on occupant sensing

More enveloping seats—support and protection

Occupant sensing

Passive restraint systems (next generation) and impact-absorbing interiors

Precrash sensor, collision-avoidance systems

Smart airbag control systems which account for position, velocity and mass—and compatible airbags

Transmission

Aluminum housing, magnesium fiber-reinforced housing

Auto/manual shift technology from racing

CVT type (4 responses)

Direct torque measurement for shifting

Electronic throttle control to reduce transmission size by 30 percent in all dimensions

Modularization with interchangeable components

Rear axle shifter—the drive for CAFE will drive more ways to be fuel efficient

Significant improvements in torque-converter design

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This comparison is not made for open-ended questions.

Discussion/Strategic considerations

Many new or improved technologies, materials, components or systems have been noted by panelists as likely to emerge in the next decade that will have significant impact on vehicle systems. Many are currently under development by manufacturers or suppliers.

The manufacturer or supplier that is able to extract from these responses those items that will enhance customer value or reduce product cost and incorporate them in their products could gain competitive advantage.

TECH-81. Please forecast the percent of North American-produced passenger cars that will have the following maintenance/durability features by the years 2002 and 2007.

	Median Response		Interquartile Range	
Vehicle Maintenance Features	**2002**	**2007**	**2002**	**2007**
100,000-mile maintenance-free engine (except oil & filters)	50%	80%	10/80%	36/99%
Chassis lubed for life of vehicle	50	75	15/80	36/100
10-year body corrosion warranty (perforation)	50	78	20/80	48/99
50,000-mile/5-year coolant	50	78	20/88	50/100
100,000-mile maintenance-free transmission (including fluids)	50	78	20/75	36/94
100,000-mile/10-year exhaust system	40	50	10/74	21/90
Chip-proof windshield	5	15	0/20	5/40

Selected edited comments

- Corrosion is still a big problem.

Discussion

Panelists forecast that a number of new vehicle maintenance features will be included on most passenger cars by 2007. These include 100,000-mile maintenance-free engine and transmission, chassis lubed for life, 10-year body corrosion warranty and 50,000-mile/5-year coolant.

Manufacturer/supplier comparison

Responses for manufacturers and suppliers are statistically significantly different for the areas noted in the following table. Please note that, whereas median values are reported in the original question, mean values are used in determining if there is a statistical difference and are compared in this analysis.

Vehicle Maintenance Features				
	2002 Mean		2007 Mean	
Feature	**Mfr.**	**Supp.**	**Mfr.**	**Supp.**
50,000-mile/5-year coolant	65%	43%	81%	60%
100,000-mile maintenance-free transmission	60	38	76	56

Manufacturers forecast higher application rates of the above items than suppliers.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Strategic considerations

Reducing required vehicle maintenance offers the opportunity to improve customer satisfaction and owner loyalty. The manufacturer that can offer these vehicle maintenance features at low or no

cost to the customer will be in an advantageous position. It is likely that many customers will consider many of these features as standard requirements in the vehicle market by 2007.

TECH-82. Please indicate your estimate of human resource deficiencies for the following skill areas currently and in 2007.

Scale: 1 = severe deficiency 5 = no deficiency

	Mean Response	
Occupation/Training	**Current**	**2007**
Systems engineer	2.2	2.4
Electrical engineer	2.8	2.6
Materials engineer	2.8	2.6
Software programmers	2.5	2.6
Manufacturing engineer	2.7	2.7
Electronics technician	2.8	2.7
Designer	2.9	2.8
CAD/CAM/CAE operator	2.7	2.8
Skilled trades	3.1	2.8
Service technician	3.0	2.9
Mechanical engineer	3.4	3.1
Chemical engineer	3.5	3.2
Industrial engineer	3.5	3.3

Selected edited comments

- A systems engineer is a band director without a band. (A systems engineer is useless the way the Big Three deploys engineers.)
- Core specialties (i.e., body-in-white engineers, vehicle development engineers, etc.) that require lengthy specific training regimens will become ever more valued.
- More training will be available via the Internet.
- Some of these current deficiencies are not acknowledged by some management groups.
- The computer industry is a major draw for new engineers. Skilled trades and technicians are not looked upon as being appealing and respected jobs, unfortunately.

Discussion

Panelists noted that there currently is at least a moderate deficiency of technical people in all areas of training and skills. The most severe shortages are for systems engineers, software programmers, manufacturing engineers and CAD/CAM/CAE operators. The least deficiency is for chemical, industrial and mechanical engineers.

By 2007, personnel deficiencies are forecast as little changed from the current situation. For most specialties, deficiencies are forecast to increase slightly.

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was not asked in previous Delphi forecasts.

Strategic considerations

An adequate supply of trained technical personnel is critical to manufacturers and suppliers as they compete in a global market. The shortages noted by panelists can have a significant impact on manufacturers' and suppliers' ability to bring increasingly more technical products to market at an affordable price. This shortage is forecast, generally, to become more serious by 2007.

If other countries are able to train adequate numbers of technical personnel, they will have a competitive advantage in the next decade. This is a challenge for American industry and educational systems. Clearly we have much work to do in education and in encouraging young people to learn. Jobs in the auto industry will require skilled people with a strong foundation and a willingness to learn throughout their careers.

TECH-83. How many hours per year will be spent in continuing education by the typical technical employee in the years 2002 and 2007?

	Median Response			Interquartile Range		
Technical Employees	**Current**	**2002**	**2007**	**Current**	**2007**	**2007**
Hours per year spent in continuing education	40	60	80	20/40	40/95	50/120

Of these hours, what percent will be spent in a classroom, virtual college (TV or internet), or correspondence course?

Continuing Education Trends						
	Median Response			Interquartile Range		
Mode of Education	**Current**	**2002**	**2007**	**Current**	**2002**	**2007**
Classroom	80%	70%	50%	60/91%	50/80%	30/70%
Virtual college	5	20	30	0/18	10/30	18/50
Correspondence	4	5	1	0/10	0/10	0/10
Total	100%					

Other Responses:

Conferences, seminars – Current: 10%; 2002: 5%; 2007: 5%

Corporate-sponsored classes – Current: 50%; 2002: 60%; 2007: 70%

On the job – Current: 75%; 2002: 75%; 2007: 65%

Shop floor – Current: 44%; 2002: 29%; 2007: 15%

Workshops – Current: 65%; 2002: 65%; 2007: 65%

Selected edited comments

- Correspondence and virtual colleges will become nearly the same.
- Informal continuing education events (plant visits, teardowns, workshops, customer research events) will continue to have the highest yield.
- More employees will spend additional time in classrooms learning multiple functions and development of systems.
- Website (GM) is coming. Tuition assistance is handled corporately, not at Delphi.

Discussion

Panelists note that the typical technical employee currently spends 40 hours per year on continuing education. This is forecast to increase to 80 hours per year by 2007.

Panelists further indicate that 80 percent of current continuing education takes place in the classroom. This is forecast to drop to 50 percent by 2007, with virtual classrooms (television or Internet) picking up most of the change in educational format.

The comment of one panelist is important in noting that "informal continuing education events such as plant visits, tear-downs, workshops and customer research events will continue to have the

highest yield."

Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

Trend from previous Delphi surveys

This question was not asked in previous Delphi forecasts.

Strategic considerations

Continuing education will increase in importance as product and process become increasingly more complex. It is also important in educating personnel on the specifics of the job that may not have been a part of formal education. Furthermore, an employee may be well trained in the technical aspects of the job through formal education, but may not know how the organization functions or understand his or her role in that organization.

The forecast that the number of hours of continuing education for an employee will double in the next decade indicates both opportunity and challenge for educational institutions and employers.

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DEFINITIONS

FOREIGN NAMEPLATES Refers to all non-U.S.-headquartered vehicle manufacturers or dealership networks regardless of production location (i.e., Honda's U.S. production should be combined with it's import vehicles).

LIGHT TRUCK Includes sport utilities, vans and pickup vehicles.

NORTH AMERICAN-PRODUCED PASSENGER CARS AND LIGHT TRUCKS Refers to all vehicles produced in the United States and Canada.

QUALITY/RELIABILITY/DURABILITY (QRD) Encompasses any customer dissatisfaction for which a vehicle is taken back to the dealership.

TRADITIONAL DOMESTIC OR BIG THREE Refers to all U.S.-headquartered (parent company) manufacturers or dealership networks regardless of production location (i.e., forecast for General Motors should include NUMMI-produced Prizms and imported Metros).

Note: "year" refers to Model Year unless otherwise specified.

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KEY WORD INDEX

Key Words	Question Number		
	Technology	Marketing	Materials
ABS(brakes)	—	25	9,20,21,23,41
ABS(plastic)	—	—	23,41
AC compressor	78	—	—
Accessory drive	6,11	—	—
Acetal	—	—	23
Acrylic	—	—	23,46
Active engine mounts	56	—	—
Actuators	34,48,72,77	—	—
Advanced features	—	43	—
Aerodynamics	6,11	48a	—
Affordability	16, 17	10,12,14,23,40b,46	10-12,22,31,33,40,42, 44
Age of vehicles	—	2	15
Air pump	78	—	—
Airbags	48	23,25,48b	9
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Alternative energy sources	13,16	—	—
Aluminum	37, 38, 62a,b	47,48a	5-7,9,12-16,20,22,24, 25,27,30,33, 34, 36, 38-42,44,45,47,49-51
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Battery	35	48b	6,7
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Body torsional frequency	32b	—	—
Bonding/joining	—	—	37,46
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CAFE (Corporate average fuel economy)	2,5,7,8,9,16,41	1,6,10,11,14,41	1,5,8,9,11,12,17-20, 22,23,27,38,39,42,44, 53
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Compact Disc player	75	—	—
Cellular phone	75	—	—
Ceramics	37, 68	—	7,12,14,22,30,31
Chassis	—	41	6,7,15,20-22,25,42,49
Coil-on-plug	61	—	—
Collision warning	50	43	—
Combustion engine	13,15	45	5-7,17,20

Key Words	Question Number		
	Technology	Marketing	Materials
Comfort	12	8,9,10,23,46,48b	7,12,14,27,28,36-39
Competition, elements of	22	—	—
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Components	25,26,27	1,29,40a,41,42	6,7,12-15,18,20,21,24, 25,27,30,38,40-42,44
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Consortia	—	—	—
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Convenience	12	8,9,17,18,20,22,46	5
Copper	—	—	22,33,50
Corrosion	—	25,35,48a	11,12,14-16,20,24,25, 34,37,39,40,49
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Drivetrain configuration	71	—	—
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Economic trends	—	1	—
Education	—	1	6,12,14,21

Key Words	Question Number		
	Technology	Marketing	Materials
Efficiency	6	26a,40a,48a	6,7,9,14,49,20
Efficiency, noise	32a	—	—
Efficiency, packaging	32a	—	—
Electric	13,75,77,78	2	—
Electric vehicles	—	7	1,4,6,10
Electrochromatic glass	56	—	—
Electronic	11,72,73,75,79	23,48a,48b	12,15
Electrorheological fluids	56	—	—
Emissions	12,13,16,65,66	6,10,41,45,48a	1,4,8,9,11,12,14,20,21, 34,47,49
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Fore-aft	—	—	—
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Gasoline	1a,13	2,3a,3b,10,40a	1,2,3,5,11,19,21,25,27, 34
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Glass	—	48a,48b	7,22,25,3941,43,46,49, 50,51
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Hydrocarbon (HC) trap	65	—	—
HSLA steel (HSS)	—	—	7,14,20,21,22,25,38, 40,41,42
Human resources	82,83	—	—

Key Words	Question Number		
	Technology	Marketing	Materials
Hybrid	13	2,7,10,48a,48b	1,4-7,10,20,22,30,35, 45,49
Ignition systems	61	—	—
Image, corporate	22	—	—
Industry structure	—	4	—
Infrastructure	1b	3a,3b,40a,43,44,45	1,6,7,10,12,14,37,39, 50-52
Injection	—	—	5,19,20,49
Intake manifold	67	—	20,23-25,30
Internet	82,83	17,19,21	—
Ionomer	—	23	23
ITS Intelligent transportation systems (IVHS)	50	43,44	9
Keyless entry	75	46	—
Lead-acid	—	—	6
Lean burn	63	—	—
Lean NOx trap	65	—	—
Legislation	16,17,42	6	4,5,8,9,10,14
Lift control	—	—	1,25
Lightweight materials	—	48a	6,7,9,12,14,17,21,22, 30,42,44,49
Loans	—	12,13,14,16	—
Magnesium	—	—	6,7,9,12,14,15,20,21, 22,24,25,27,30,39,41, 42,45
Maintenance	—	2,3a,19,22,24,36	1,26
Manufacturing	—	1,4,5,7,12,14,38,39, 40b,45,48a	6,7,9,11-14,18-21,24, 30,33,36-38,47,49
Market segments	—	7,44,46	21
Market share	—	2,6,14,22,31,32,33,45	5,14,17,24
Marketing divisions	—	4	—
Materials	12,42	40b,45,48a,48b	6,7,9,11,14,18,19,25, 27,29,32-34,43,49,50
Materials change	37	—	12
Math base	33a	—	—
Message system	50	43	—
Metal matrix composite (MMC)	—	—	22,25,30,44
Metal substrate	64	—	—
Miller cycle	56	—	—
Motors, electric	77,78	—	—
Multiplexed	73,74	—	—
Nameplate offerings	—	4,7	—
Natural gas	13	—	1,5
Navigation	50	43,44,46,48b	—

Key Words	Question Number		
	Technology	Marketing	Materials
Nodular iron	—	—	20,44
Noise cancellation	79	—	—
NOx catalyst	63	—	5,25
Nylon	—	—	23,25,41
Occupant restraint	16	6	8,9
Oil pan	67	—	20,24,25,30
Outsourcing	—	—	21
Owner loyalty	—	—	6
Ownership	—	13,15,18,19,24,26a,35, 36,45	51
Paint	—	48a	9,13-16,20,39,46-49,52
Particulate controls	65	—	—
Parts	25,26	8,29,40a	7,10,12-16,18-20,23, 25,27,36,37,39,41,49, 50-52
PC/PBT	—	—	23
Performance	22	5,6,25,26,41,42,45,46, 47	4-7,9,11,12,14-18,20, 21,25,26,35,37,41,44, 48,49,53
Phenolic	—	—	23,41,44
Piston	67,68	—	30,31,44
Platforms	18,19	4,7,10,28,29,40b,48a	20,35,40
PNGV (Partnership for a New Generation Vehicle)	9,10,11,12	3a	7,8,14,17,20,21
Polycarbonate	—	—	23,41,43
Plastic/composite	37,38,39,67	—	7,12,21
Polyester elastomer	—	—	23
Polyester thermoplastic	—	—	23
Polyester thermoset	—	—	23
Polyethylene	—	—	23,41
Polymer based	37,67	—	—
Polypropylene	—	—	20,23,25,26,41
Polyurea	—	—	23
Powdered metal	37,55	—	22,25,30,32
Powertrain material applications	—	29,39,41	—
PPO/nylon	—	—	23
PPO/styrene	—	—	23
Prices	—	1,2,3a,3b,10,11,12,13, 14,17,21,23,40b,42,43, 44,45	1,7,16,24
Product design	23,24	3a.6	12,14,51,52
Product differentiation	—	7,23,26a,26b,29	—
Product liability	16	6	8,11
Production, volumes	—	—	12

Key Words	Question Number		
	Technology	Marketing	Materials
Production development	—	7,37	
Production process	12	—	5
Propane	13	—	—
Prototypes	19,33b	28	—
Push rod	54,55	—	—
PVC	—	—	14,24,41
QRD	22	—	—
Quality	—	2,4,5,8,23,24,26a,26b, 35,37,40b,46	3,9,10,11,12,18,21,28, 29,45,49
Recyclability	42	2,6,45	6,7,9-12,14,20,21,23, 37-39,41,46,50-53
Redesign	57	28,30,37,48a	6,7,14,21,27,44
Reformulated gasoline	—	—	1,3
Regionalization	16,17	6	—
Regulation	16,17,42	1,6,10,11,12,14,40b	3,4,6-12,14,17,18,20, 21,41,47,49
Repair	—	3a,18,19,22,23,40b,44, 48a	1,2,6,12,14,16,25,37, 39,41,49
Retail prices	—	11,14	—
Retail sales	—	17	—
Ride and handling	22	10,26a	—
Roller lifters	55	—	—
Rolling/resistance	6,11	—	—
Rubber	—	—	22,41
Safety	22	6,23,25,	6-13,17,21,36-38,41, 43-46,49,53
Sales	—	2,5,7,8,10,13,17,18,19, 23,30,31,32,33,34,36, 38,39	4,6,12,13,15,17
Sales personnel	—	18	—
Sales procedures	—	18	—
Seals	68	—	31
Selling	—	4,5,7,17,18,20,23,24, 28,36,38	19
Sensors	72a,b	42	—
Service	—	17,18,19,20,22,23,24, 25,	11-15
Sequential shift	70	—	—
Sharing	18	7,29	6,7,
Skills	—	18	50,23,41,
Spark plugs	61	—	—
Springs	44	—	25,42
Stainless Steel	—	—	7,14,20,22,25,30,44
Standardization	34	29	12
Standards	16	5,10,23,24,40b,45	1,3,4,6,8-10,12,14,18, 22,24,27,39,46,48,51

Key Words	Question Number		
	Technology	Marketing	Materials
Start-up catalyst	—	—	64
Steel	37,38,39	25,47	6,7,12-16,18,20-25,29, 30,34,36-42,44,45, 47-52
Steering	78	46	20,24-26,42
Stirling	15	—	—
Strategic planning	—	1	—
Stratified charge	56	—	—
Styling	—	8,9,23,28,30,48a,48b	6,11,12,14,20,25,39, 40,42,44,45
Sub-assemblies	25,26,27	—	—
Supercharged/ Supercharger	6	—	—
Suppliers	—	1,2,3a,3b,4,5,6,7,8,9, 10,11,12,13,14,15,16, 17,18,19,20,21,22,24, 25,26a,26b,27,28,29, 30,31,32,33,34,35,36, 37,38,39,40a,40b,41, 42,43,44,45,46,47,48a	7,10-14,18,19,21,22, 24,25,36
Suspension	44	7,41	20,25,27,41,42
Systems engineering	35	—	—
Taxes	1a	3a,3b,40b	1,2,11,12,17,21,23
Technology leadership	31	—	—
Thermoplastic	—	—	6,14,20-23,25,38-41, 49-52
Thermoset	—	—	22,23,25,38-41,50,52
Tires	6,11,47	47,48a	7,10,22,25,27,30
Titanium	—	—	6,7,9,25
Toll collection	50	43	—
Tooling	28	—	6,12,14,37,39,49
Torque converter	70	—	—
TPO	—	—	23,25,40,41,49,52,53
Traction control	46	42,44	—
Trade	—	1,5,12,17,39,40a,40b	—
Transaction prices	—	12	—
Transmission	6,69	—	—
Transverse	—	—	7,9,15,20,24-26,32,33
Trends	—	1,2,4,6,10,13,20,22, 26a,35,36,47,	40
Truck attributes	—	9,10,27	—
Turbine	15,68	—	7,12,31
Turbocharger	6,60	41	31
Two-stroke engine	56	—	—
Urethane	—	—	23,41,42,45,46,51

Key Words	Question Number		
	Technology	Marketing	Materials
Value of 1 mpg improvement	—	—	8
Value of pound saved	—	—	41
Valve covers	67	—	—
Valves per cylinder	53	—	—
Valvetrain	54,68	—	31,32
Vehicle attributes	—	10,41,42,44,45,46,47, 48a,48b	—
Vehicle demand	—	2	—
Vehicle features	—	43,47	—
Vehicle integrity	16	6	8
Vehicle production	—	5	5
Vehicle servicing	—	23	—
Vehicle use	—	2	—
Virtual college	83	—	—
Voice activated	75	48b	—
Voltage, system	76	—	—
Water pump	78	—	—
Weight reduction/weight	6,7,11,40,41	—	6,7,9,12,14,17,18,20, 21,27,28,30,38,41,44, 45,50
Wheels	—	47,48a	6,7,20,24,25,42,45,49
Wrist pins	68	—	31
Zinc	—	—	20,22,34,49,50,51