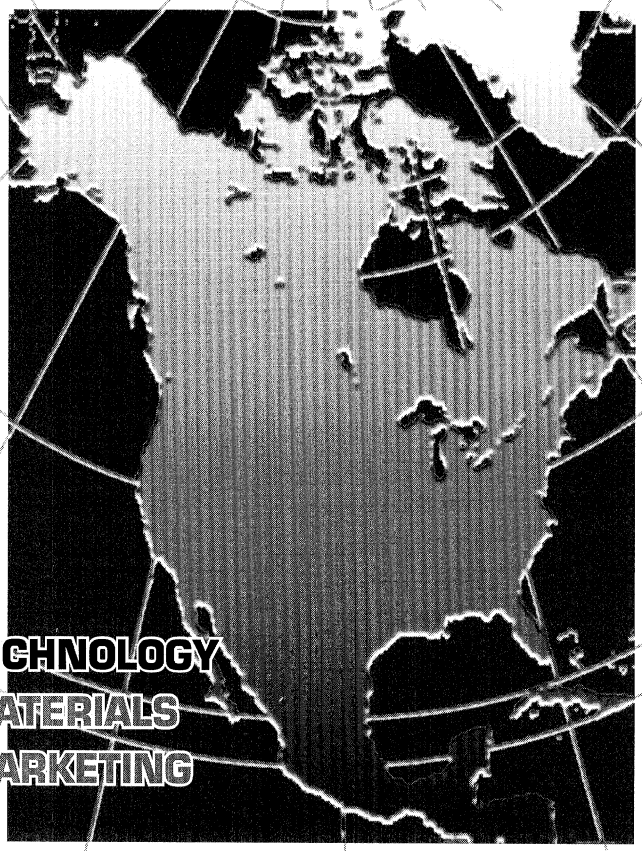
UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE

Forecast and Analysis of the North American Automotive Industry

For 2004 and 2009

Delphi X: Tenth in a Series



TECHNOLOGY
MATERIALS
MARKETING

Office for the Study of
Automotive Transportation

Delphi X Forecast and Analysis

of the

North American Automotive Industry

VOLUME 1: TECHNOLOGY

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The Office for the Study of Automotive Transportation (OSAT), a division of the University of Michigans Transportation Research Institute, focuses on the future of the international automotive industry. Its overall objectives are to provide academic research, information resources, industry analyses and communication forums that meet the continually changing needs of the international automotive and automotive-related industries. In addition, OSAT serves as a link between the University and its many external communities, including industry, labor, government, and the media.

For further information, please contact:

Office for the Study of Automotive Transportation

University of Michigan

Transportation Research Institute

Ann Arbor, MI 48104-3213

Telephone: (734) 764-5592

Fax: (734) 615-4003

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Dave E. Cole, Director
Office for the Study of Automotive Transportation
Coauthor, Volume I: Technology

Gerald F. Londal
Coauthor, Volume I: Technology

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FOREWORD

Delphi X 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. For the first time in a Delphi report, the panelists also includes top Automotive Dealers. 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 the tenth 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, Delphi VIII in 1996, and Delphi IX in 1998. With Delphi X, a new approach has been implemented to stagger the release of each of the three volumes so that they will be released within a year of when they are started (rather than two years) but not all on the same date.

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 X 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 likely will be. In retrospective review some areas (such as gas prices) have been predicted less accurately than others, yet the views of what the future will be influence decision makers of today.

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, interative 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 we do not mean 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 86 Technology X panel members are as follows: 22 percent of the technology panel was composed of CEOs, presidents, or vice presidents; 22 percent were directors and executives, 44 percent were managers, supervisors or chief

engineers; 7 percent were engineers, senior technicians or specialists; and 5 percent of the panel was made up of consultants. Approximately 40 percent of the Delphi X panelists were employed by vehicle manufacturers; 55 percent by components and parts suppliers; and 6 percent were others (i.e., consultants 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 an 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.

Results summary. 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 X 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.

Trend from previous Delphi surveys. A single Delphi survey is a snapshot that 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 X 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

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EXECUTIVE SUMMARY

Automobile manufacturers and suppliers will continue to face many formidable challenges in the next decade as they address environmental challenges, tough global competition, and more demanding customers. Furthermore, shortages of capital and skilled human resources and time pressures to do more, do it better, and yet faster exacerbate their challenges. *The Delphi X Forecast and Analysis of the U.S. Automotive Industry: Technology* identifies many issues facing the industry and provides insight as to expected 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. 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 rapidly changing technologies to reduce cost and improve customer satisfaction (increase value) will certainly have a competitive advantage.

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

I. STRATEGIC PLANNING FACTORS

Fuel prices are expected to increase steadily, but moderately, to $1.50 per gallon for regular unleaded gasoline by 2009. Electric-vehicle penetration is forecast to reach 1 percent, and hybrid electric/combustion engine vehicles 3 percent in the same time frame. Furthermore, diesel engines are forecast for 2 percent of passenger cars and 5 percent of light trucks by 2009.

Emissions, fuel economy, and safety standards are expected to become more restrictive over the next ten years. CAFE standards are expected to increase 16 percent (32 mpg) and 26 percent (26 mpg) by 2009 for passenger cars and light trucks/vans, respectively. This is in contrast to stable passenger-car CAFE standards of the past ten years and an increase of less than 5.8 percent in the last 16 years. Increased passenger car CAFE standards are forecast to present a major challenge to domestic and European manufacturers, whereas Japanese manufacturers are forecast to more easily meet these standards, reflecting the large volume of small vehicles that they sell and their use of smaller, lightweight powertrains.

Considering the PNGV agreement between the domestic manufacturers and the federal government to pursue development of clean, super-efficient passenger cars, 53 percent of panelists forecast that the goal of 80 mpg can be achieved by the year 2010.

Weight reduction and improved engine efficiency are forecast to make the greatest contributions to improved fuel economy with current powertrains. Hybrid powertrains and energy storage are expected to provide fuel economy benefits of 15 and 10 percent, respectively, on some vehicles by 2009. Cost, reliability, and battery technology are forecast to be the major challenges for development of hybrid vehicles.

Legislation and regulations to require changes in the recyclability of automotive materials are considered likely in several areas by 2009.

Several elements of competition are forecast to be important in 2009, including quality/ reliability/durability, safety, and cost to the manufacturer.

II. ENGINEERING AND SOURCING ISSUES

Panelists believe that 70 percent of 2009 product design and engineering by Ford, GM, and DaimlerChrysler for North American-produced passenger cars will be done in North America, compared with 80 percent today. Foreign-owned vehicle manufacturers are expected to conduct 30 percent of their product design and engineering for North American-produced passenger cars in North America, compared with 15 percent today.

The Big Three vehicle manufacturers are forecast to source 60 percent of parts, components, and subassemblies from the United States, Canada, and Mexico in 2009, compared with 70 percent currently. North American production operations of Japanese-owned vehicle manufacturers are forecast to source 40 percent of parts, components, and subassemblies from Japan in 2009, compared with 50 percent today. Sourcing from North America is expected to be unchanged at 40 percent. Sourcing of components and subassemblies from Mexico by traditional domestic and foreign manufacturers is expected to expand from 15 percent and 11 percent, respectively, to 25 percent by 2009.

Outsourcing of components is forecast to increase to 50 percent for first-tier suppliers compared with 30 percent currently. Outsourcing of components from OEMs is forecast to have a more modest increase to 55 percent from 50 percent currently. Outsourcing of subsystems/modules by first-tier suppliers is forecast to increase to 30 percent from 10 percent currently.

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 8 months currently to 4 months by 2009. Current development cycle times for the United States and Japan are estimated at 38 months and 30 months, respectively.

Panelists believe Japan, North America, and Western Europe have similar product-technology today. Western Europe and North America are forecast to have a slight product technology lead over Japan in 2009. Japan is thought to have the best process technology, and their lead is forecast to continue through 2009.

The proportion of vehicle-engineering activities using math- and computer-based tools (CAE, excluding CAD) is forecast to increase from 40 percent currently to 70 percent by 2009. The number of vehicle prototypes is forecast to decrease by 40 percent by 2009 as a result of improved simulation tools.

III. MATERIALS AND RECYCLING

Panelists forecast reductions in steel and cast-iron use of 15 percent and 20 percent, respectively, and increases in the uses of aluminum and plastics/composites of 18 percent and 20 percent, respectively, in the next decade if CAFÉ increases to 35 mpg. 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 reduction of 5 percent is forecast for passenger cars by 2009. The weight of light trucks is expected to be unchanged. The value of a pound of weight saved in a vehicle is forecast to escalate from $1.00 per pound today to $3.00 per pound in 2009, assuming a CAFE requirement of 35 mpg.

IV. BODY AND CHASSIS PRODUCT TRENDS

The integral body/frame is expected to remain the major passenger-car platform through 2009. 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.

For sport utility vehicles, separate body/frame construction is forecast to be used in most vehicles (60 percent) by 2009, but use of integral body/frame or unibody construction is expected to increase. Integral body/frame construction is forecast for most minivans (89 percent) in 2009, a modest increase over current applications.

MacPherson strut front suspensions are expected to continue their dominant position in passenger cars (75 percent in 2009), but increased penetration of twin A-arm is forecast. Rear independent suspensions in passenger cars are forecast to increase from 60 percent currently to 70 percent in 2009. Electrical/electronic power steering and hydraulic power steering with electronic control are expected to achieve penetrations of 20 percent and 15 percent respectively by 2009. Passive-driver selected suspensions are forecast to attain penetrations of 19 percent by 2009.

Antilock-brake penetration on passenger cars is forecast at 80 percent in 2009, while traction control is expected to see an application rate of 40 percent in the same time frame. Four-wheel antilock brakes are expected on 85 percent of light trucks in 2009 compared with 67 percent today.

By 2009, panelists expect a growing application of tire failure sensing devices (20 percent), puncture-resistant/self-sealing tires (20 percent), and run-flat tires (30 percent).

V. SAFETY

Side airbags are forecast for 35 percent of passenger cars and 20 percent of light trucks by 2009. Passenger-side airbags are forecast on 90 percent of light trucks in 2009. Limited 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 time frame. It was assumed that all passenger cars would have airbags for the driver and front passenger and that all light trucks would have driver-side airbags.

Other safety features such as in-vehicle message systems, adaptive cruise control and collision warning systems are envisioned in 15 to 20 percent of new vehicles by 2009.

VI. POWERTRAIN/DRIVETRAIN

For passenger cars, eight-cylinder engine usage is forecast to decline to 7 percent by 2009, with four-cylinder engine penetration increasing slightly. Six-cylinder engine penetration is forecast to be unchanged. Similar trends are forecast for light trucks, but with eight-cylinder engine usage at about five 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.

Port fuel injection is forecast in 85 percent of passenger cars with spark-ignited engines by 2009, with the balance utilizing direct cylinder injection (gasoline direct injection). A similar trend is forecast for light trucks.

Turbocharging and supercharging of passenger car engines are expected to see minimal application of just 1 percent and 3 percent, respectively, by 2009. On the other hand, four-valve-per-cylinder engines are expected on 50 percent of passenger car engines, compared with 39 percent in 1998. The increase in multivalve engines is certainly a factor in the low expectations for turbochargers and superchargers.

From 1998 to 2009, push-rod valve-actuation penetration is expected to decrease from 56 percent to 40 percent in engines with a "V" configuration, while single- and dual-overhead cam penetrations are forecast to expand to 22 percent and 37 percent respectively. For "in-line" engines, push-rod valve actuation is expected to decrease from 8 percent in 1998 to 3 percent in 2009, with single- and dual-overhead-cam penetrations representing 45 percent and 51 percent, respectively, in 2009. Variable valve timing in passenger car engines is forecast at 25 percent in 2009 compared with a current estimate of 5 percent.

The use of distributorless ignition systems on spark-ignited engines is expected to increase to 90 percent in passenger cars and light trucks by 2009. In the same time frame, knock/adaptive control is forecast for 70 to 73 percent of passenger cars and light trucks. By 2009, cylinder pressure control and individual cylinder control of ignition timing are forecast to see modest applications of 7 to 20 percent, whereas coil-on-plug designs are forecast for 30 percent of passenger cars and 20 percent of light trucks. Furthermore, features such as balance shafts, hollow camshafts, and roller lifters are all expected to achieve wider application in the next decade.

The use of aluminum in cylinder heads and blocks in passenger car engines is expected to increase to 95 percent and 50 percent respectively by the year 2009. 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 by the year 2009.

Electrically heated catalytic converters and start-up converters are expected to be required in some applications to meet both federal and California emission standards over the next decade. Panelists forecast that the cost of meeting tier 2 emission standards may be as high as 7 percent of total vehicle cost by 2009.

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 2 percent three speeds forecast for 2009. Five-speed automatic transmissions are forecast to emerge in upscale vehicles (5 percent). Continuously variable transmissions are forecast in 8 percent of passenger cars by 2009. In that same timeframe, sequential shift automatic transmissions and automatic transmissions without torque converters are forecast for 10 percent of passenger cars.

Transmission configurations for light trucks are forecast to be very similar to those of passenger cars in the next decade.

In the opinion of our panelists, front engine, front drive will continue to be the dominant drivetrain configuration in passenger cars, at 91 percent penetration.

VII. ELECTRICAL/ELECTRONICS

Combined electrical and electronic cost, as a percent of total vehicle cost, is forecast to expand from a current estimate of 20 percent to 32 percent in 2009. Vehicle electronic content is expected to continue to grow, from a 1998 estimate of 10 percent of total vehicle

cost to 20 percent by 2009. Vehicles with at least one major multiplexed power system are forecast to expand from a current market estimate of 0.5 percent to 4 percent by 2009. 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. Increased systems voltage is forecast for up to 30 percent of vehicles in the next decade. The number of electric motors in a vehicle is anticipated to increase approximately 35 percent by the year 2009.

Telematics are forecast to be used in most luxury vehicles by 2009, and as many as 30 percent of nonluxury vehicles. These features are forecast to cost from 3 to 5 percent of the cost of the vehicle.

Panelists identify numerous applications of microelectromechanical systems (MEMS) that will be developed in the next five years.

VIII. OTHER ISSUES

The following vehicle maintenance features are forecast for 75 percent or more of passenger cars by 2009: 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 are 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.

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I. STRATEGIC PLANNING FACTORS

TECH-1 Please estimate United States retail fuel prices, per gallon, for 2004 and 2009, including fuel tax. (Please use constant 1999 dollars without adjusting for inflation.)

UNLEADED GASOLINE	1998*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
REGULAR	$1.07	$1.25	$1.50	$1.20/1.50	$1.30/1.90
PREMIUM	1.26	1.46	1.75	1.36/1.75	1.51/2.20

*Source: U.S. Energy Information Administration, National Average, Jan.-Nov. 1998.

SELECTED EDITED COMMENTS

Increase

- Current U.S. gasoline prices are out of step with the rest of the world and unrealistically low. The demand for cleaner gasoline will cause prices to rise.
- Fuel tax may increase even if crude oil price remains constant.
- Increase when requirements for global reductions are implemented.
- Most of the increase will be due to taxation.
- Unless there is an unpredictable "political event," I would expect only very modest increases in the cost of fuel as global fuel consumption increases. Previous predictions of increasing energy costs have proven unfounded, at least so far, excluding short-term perturbations.

Stay the same

- I anticipate a stable condition.
- Unless there is a major disruption (e.g., another Middle East war), a significant increase in U.S. fuel taxes, which is politically unlikely, fuel prices will remain virtually unchanged.

Other

- Gasoline prices have no relationship to actual value but are the result of taxation and price setting by the federal, state, and local governments. The actual price of gasoline is less than bottled water.
- Some small but significant efforts to match world averages in order to ease national "peer pressure."
- The drivers for fuel price are largely outside the realm of the automotive industry.
- The price of fuel is so political that it is impossible to predict.
- These numbers could change dramatically if OPEC ever gets their act together, or if there is real trouble in the Middle East. (2 responses)
- This is solely dependent on fuel availability and OPEC.

RESULTS SUMMARY

Delphi X panelists anticipate the prices of regular and premium gasoline to increase by approximately 40 percent in constant 1998 dollars by 2009. This increase will add about 3 percent per year above the inflation rate to the price of gasoline.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the estimate of the price of premium gasoline for 2004, as shown in the following table.

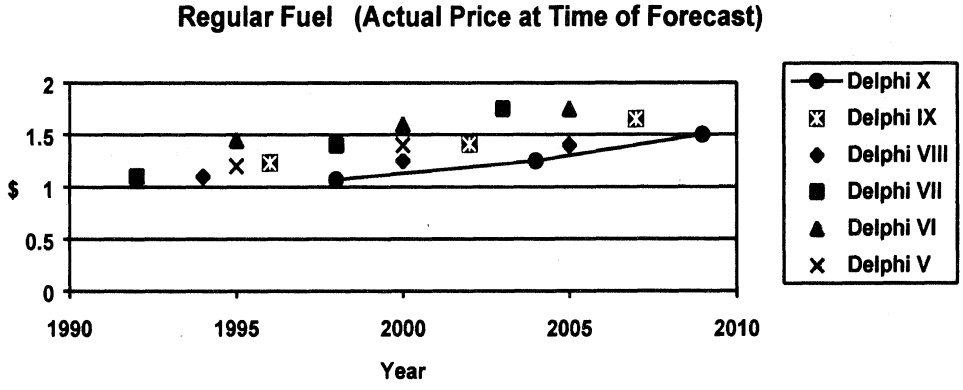
UNLEADEAD GASOLINE	MANUFACTURER MEAN	SUPPLIER MEAN
PREMIUM 2004	1.62	1.50

Manufacturers forecast a higher price for premium gasoline in 2004 than suppliers. Please note that whereas median values are reported in the original question, mean values are used to determine whether there are statistical differences and are compared in this analysis.

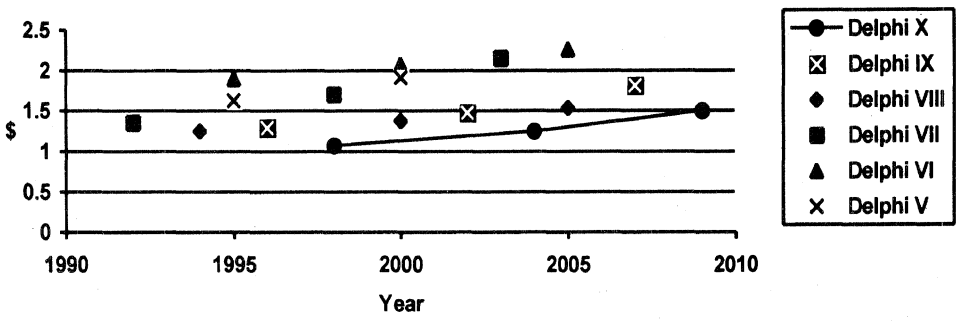
TREND FROM PREVIOUS DELPHI SURVEYS

The following graphs compare the prices of gasoline for this and the previous five Delphi forecasts in current dollars at the time of the survey and also in constant 1999 dollars.

Unleaded Regular Gasoline:

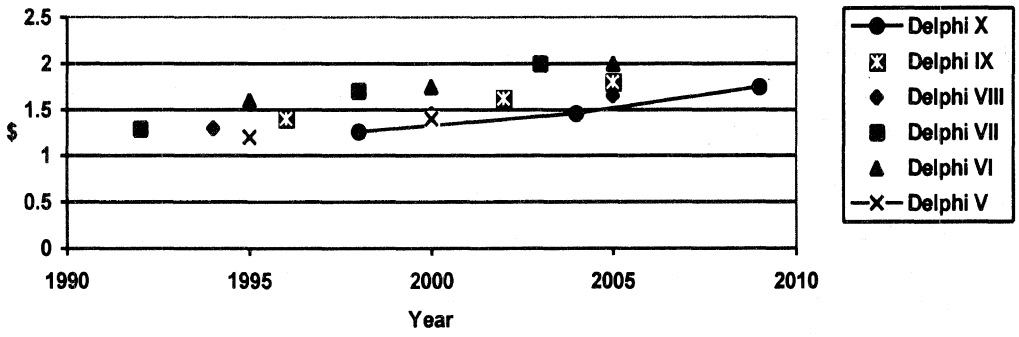


Regular Fuel Price Forecast (1999 Dollars)

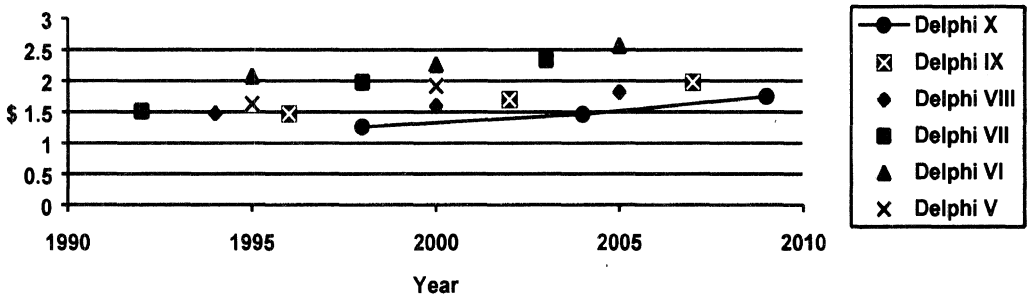


Unleaded Premium Gasoline:

Premium Fuel (Actual Price at Time of Forecast)



Premium Fuel Price Forecast (1999 Dollars)



Prices for regular and premium fuels are forecast to increase, but not to levels forecast in previous Delphi surveys. In fact, actual prices of regular and premium fuel were lower in 1998 than in 1992, the baseline year for Delphi VII. Recent forecasts for increasing fuel prices have not come to pass. The 1979 Delphi forecast for unleaded fuel for 1990 was

$4.29 per gallon. This forecast was made at a time of severe petroleum restrictions by OPEC countries and estimates of severe oil shortages in future years.

STRATEGIC CONSIDERATIONS

In spite of the decrease in fuel prices in the last few years, there have been significant price swings in the past year. The price of regular fuel was as little as $.80 per gallon in February of 1999 in some locations. The price of gasoline in the United States remains significantly below prices seen in most other parts of the world. This is forecast to continue through 2009.

Low fuel prices will continue to cause a challenge to automobile manufacturers in meeting CAFE standards. Consumers will continue to buy large passenger cars and light trucks, as the annual cost of fuel for these vehicles is affordable. This will also exacerbate efforts to reduce the emissions of greenhouse gases (carbon dioxide) from vehicles.

Political or economic perturbations in oil-producing countries could drastically and rapidly impact the price of fuel. Panelists apparently do not foresee such events in the near future, although a number raise this specter in their comments. As one panelist commented, "the price of fuel is so political that it is impossible to predict." This makes long-range planning for automobile manufacturers very difficult.

Comments have been made in the past that fuel-price forecasts should only be made by fuel suppliers, as they are in the best position to know. However, it is important to note that the prices forecast in this survey are most likely the prices on which future product decisions are being made because the forecasts come from those within the automobile industry.

The future trends in fuel pricing are likely to be extremely volatile as the recent significant increases in gasoline and diesel fuel would attest. Clearly there are many factors outside of the control of governments and energy and auto companies that will define the future as we have seen with the recent supply cutbacks by OPEC. This suggests a future of uncertainty and the importance of preparing alternative strategies and increasing agility to be able to take advantage of this uncertainty.

TECH-2 What do you expect CAFE (Corporate Average Fuel Economy) standards for passenger cars and light trucks and minivans will be in 2004 and 2009?

CAFE STANDARDS					
VEHICLE TYPE	1998*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
PASSENGER CARS	27.5 mpg	29	32	28/30	30/35
LIGHT TRUCKS AND MINIVANS	20.7 mpg	22.5	26	22/25	24/29

*source: U.S. Environmental Protection Agency.

SELECTED EDITED COMMENTS

Increase

- Congress will temper the rate of increase beyond 2004.
- Expect requirements for small fleets of 45-65-mile/gallon vehicles starting around 2005 (in light of Kyoto and PNGV).
- I expect light-truck standards will equal passenger car standards by 2009, forcing manufacturers to achieve one corporate average.
- I would like to see passenger cars go to 35-40 mpg CAFE, but there is no political drive or desire by politicians or auto-makers, particularly with gasoline available and cheap.
- If Al Gore is elected president in 2000, he will push for higher CAFE standards. (2 responses)

Stay the same

- Barring another energy crisis, which seems unlikely, these numbers shouldn't change much.

Other

- Again, who knows the correct political answer?
- Better numbers can be achieved with some alternative fuels, but it will be 20 years or more before the real effect can be felt fleetwide.
- The Big Three only meet today's standards by borrowing past and future credits. There will be a lot of pressure to relax, probably indirectly, by continuing diesel engine waivers.
- The standards depend on the next elections, however, I can see them going to one number for all vehicles sold.
- With the vehicle mix shifting toward more "trucks" and fewer conventional "cars," the federal government is likely going to redefine what is classified as a truck versus a car to better comprehend actual vehicle usage. The market pull for larger trucks (at least some), more features, and more performance hurts ability to increase (truck) fuel economy; as does reduced market pull for small cars (at least in North America when the cost of gas is less than bottled water).

RESULTS SUMMARY

Passenger-car CAFE standards have been unchanged since 1990 and light truck CAFE standards since 1991. Panelists forecast increases in CAFE standards for passenger cars and light trucks of 16.4 percent and 25.6 percent, respectively, by 2009.

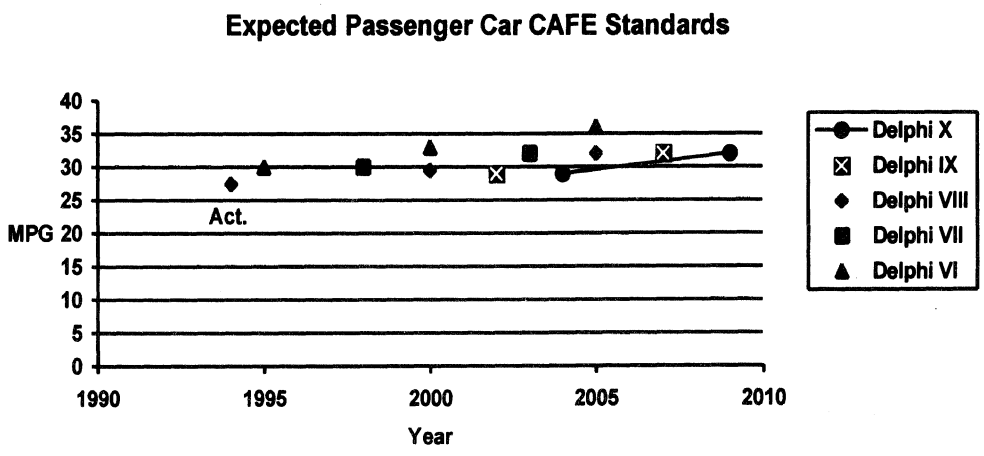
MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

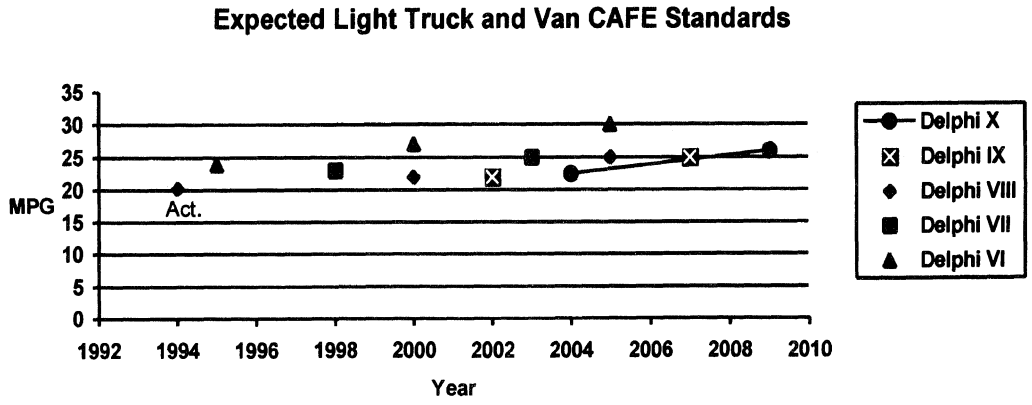
TREND FROM PREVIOUS DELPHI SURVEYS

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

Passenger Cars:



Light Trucks and Vans:



The expected increase in CAFE standards forecast in the current survey is similar to increases forecast in past surveys. The increases forecast in Delphi VI and Delphi VII have not yet developed.

STRATEGIC CONSIDERATIONS

As noted in the comments, politics are an important factor in setting CAFE standards. It is therefore difficult to forecast change. It is important to note, however, what the automobile industry expects CAFE standards to be. It is these expectations that will drive decisions on future vehicle designs.

When CAFE was first implemented, the driving force was conservation of fuel in order to limit dependence on foreign oil, conserve a limited resource, and reduce the balance-of-payments deficit caused by the purchase of foreign oil. A more recent consideration is concern for global warming. Reducing fuel consumption is the only known method of reducing carbon dioxide emissions from vehicles using hydrocarbon fuels. As noted in the previous question, low current and forecast prices of fuel encourage consumers to purchase vehicles that are less fuel-efficient, but offer other advantages. Thus, the CAFE approach creates a fundamental conflict between auto manufacturers and their customers.

It is politically more expedient for legislators to ask the automobile manufacturers to solve the problem of fuel consumption, whereas increased fuel prices would be, in theory, a more effective tool. This is the case in other parts of the world, such as Japan and Europe.

A number of panelists commented that many light trucks may soon be classified as passenger cars. This would make it substantially more difficult for manufacturers to meet passenger car CAFE.

See TECH-3 for additional considerations regarding CAFE.

TECH-3 Which passenger car and light-truck CAFE standards can the Big Three manufacturers (Ford, GM, DaimlerChrysler) and other full-line vehicle importers reach, with reasonable effort, in 2004 and 2009? (Reasonable effort means utilizing practical technology, avoiding substantial reduction in passenger and luggage space, and avoiding excessive costs for manufacturers and suppliers.)

MANUFACTURERS	1998 MPG ACHIEVED*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004 MPG	2009 MPG	2004 MPG	2009 MPG
PASSENGER CARS					
EUROPEAN - FOREIGN AND DOMESTIC (EXCLUDE DAIMLERCHRYSLER)	27.5	30	32	28.5/30.3	30/35
FORD, GM, DAIMLERCHRYSLER	28.1	30	33	29/31	31/35
JAPANESE - FOREIGN AND DOMESTIC	29.8	32	35	31/33	33/37
LIGHT TRUCKS					
EUROPEAN - FOREIGN AND DOMESTIC (EXCLUDE DAIMLERCHRYSLER)	17.2	20	22	18.3/21.7	20/25
FORD, GM, DAIMLERCHRYSLER	20.5	22	25	22/23	24/27
JAPANESE - FOREIGN AND DOMESTIC	22.9	25	27	24/25.5	26/30

*Source: American Automobile Manufacturers Association; Motor Vehicle Facts & Figures 1998; Automotive News, Jan. 11, 1999.

SELECTED EDITED COMMENTS

- Aerodynamic improvements and continuing improvements in friction-reduction engine control and emissions will continue to provide slight increases in MPG (2 to 3 mpg). The big jump will come from more significant changes in powertrains, such as CVTs, hybrids, GDI small displacement, etc.
- High-torque capacity CVTs are the enabling technology for light-truck fuel economy increases, especially for the U.S. and European light truck manufacturers, whose products are generally heavy and whose light trucks have larger engines. The first implementation of CVTs should be good for 10 percent, while optimization of the total powertrain around the CVT should find another 5 to10 percent. GDI is also a very good possibility.
- North American vehicle manufacturers do not accept many technical advances the way European and Japanese vehicle makers do. Since practical technology is and must be defined by how much profit can be realized on the vehicle, the real constraints are how profitably can an OEM implement efficiency-improving technologies.
- Passenger cars 2004: The rate of introduction of new technology limited by investment in manufacturing plants ($500M to $1B per plant). Trucks 2006: Japanese building "bigger" trucks. Trucks 2009: Very limited application of diesels. There are very, very few hybrids.
- Projections will increasingly depend upon the influence of emissions and CAFE requirements. Witness the restrictions imposed on light-truck fuel-economy opportunities when California ARB eliminated TLEV standards (diesel powertrains) in the LEV II ruling.
- The distinction between what U.S. and foreign manufacturers can achieve will continue to diminish as the industry continues to "globalize."
- The real criterion is, "What would customers be willing to buy?"

- The technologies in place today, coupled with improved control algorithms and microprocessors, will have further impact.
- This depends heavily on emission levels!
- This depends on the product portfolio mix (size), technology applications (fuel cells, hybrid, optimized alternative fuels), other fuel- economy-technology applications, and legal constraints (i.e., on diesels and fuel technology applications/cleanliness, etc.).
- This issue can be answered with materials as well as with technology. If the weight is reduced 20 percent the MPG will rise approximately 20 percent.
- What fuel economy can be achieved is a very different question than what fuel economy will be achieved. Lack of customer "pull" due to low energy prices in North America will constrain the manufacturers willingness to spend for increased energy efficiency or make other tradeoffs to favor fuel economy.

RESULTS SUMMARY

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 for 2004 and 2009.

Passenger Car:

ACHIEVABLE PASSENGER CAR CAFE			
	1998 MPG*	MEDIAN RESPONSE	
		2004	2009
CAFE REQUIREMENT (FORECAST) (REF.: TECH-2)	27.5	29	32
EUROPEAN-FOREIGN AND DOMESTIC (EXC. DAIMLERCHRYSLER)	27.5	30	32
FORD, GM, DAIMLERCHRYSLER	28.1	30	33
JAPANESE-FOREIGN AND DOMESTIC	29.8	32	35

*Source: American Automobile Manufacturers Association; Motor Vehicle Facts and Figures 1998; Ward's Automotive Reports, Jan. 11, 1999.

Attainable *passenger car* CAFE levels are forecast to be as follows for the years 2004 and 2009:

European – foreign and domestic → at or above the standard

Ford, GM, DaimlerChrysler → somewhat above the standard

Japanese – foreign and domestic → above the standard

Light Trucks:

ACHIEVABLE LIGHT TRUCK CAFÉ			
	1998 MPG*	MEDIAN RESPONSE	
		2004	2009
CAFE REQUIREMENT (FORECAST) (REF.: TECH-2)	20.7	22.5	26
EUROPEAN-FOREIGN AND DOMESTIC (EXC.DAIMLERCHRYSLER)	17.2	20	22
FORD, GM, DAIMLERCHRYSLER	20.5	22	25
JAPANESE-FOREIGN AND DOMESTIC	22.9	25	27

*Source: American Automobile Manufacturers Association; Motor Vehicle Facts and Figures 1998; Ward's Automotive Reports, Jan. 11, 1999.

Attainable *light truck* CAFE levels are forecast to be as follows for the years 2004 and 2009:

European – foreign and domestic → well below the standard

Ford, GM, DaimlerChrysler → below the standard

Japanese – foreign and domestic → above the standard

MANUFACTURER/SUPPLIER COMPARISON

Responses for manufacturers and suppliers are statistically significantly different for the areas noted in the following table.

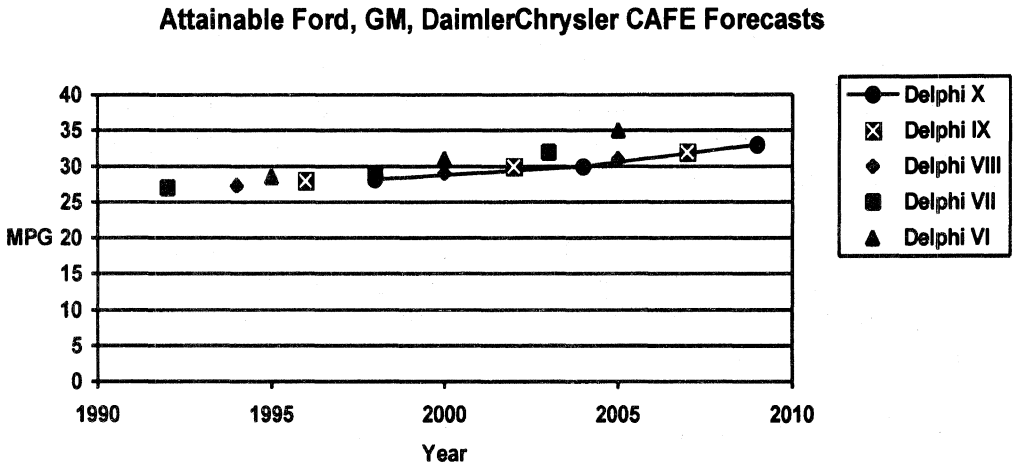
ATTAINABLE CAFE STANDARDS FORECAST – 2004 MEAN MPG		
MANUFACTURERS	PANELISTS	
	MEDIAN RESPONSE	
	MFR.	SUPP.
PASSENGER CARS		
EUROPEAN – FOREIGN AND DOMESTIC	29.3	30.3
FORD, GM, DAIMLERCHRYSLER	29.8	30.6

Suppliers forecast higher attainable fuel economy levels than manufacturers for European and domestic manufacturers.

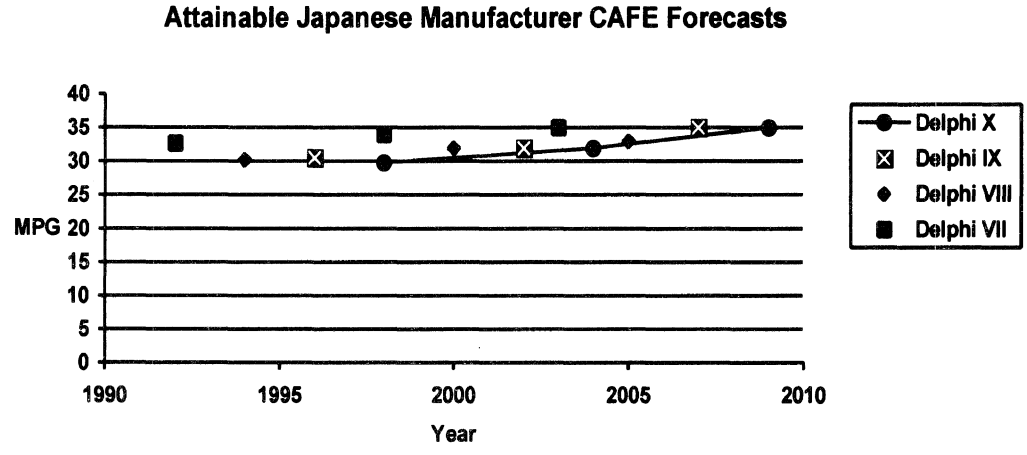
TREND FROM PREVIOUS DELPHI SURVEYS

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

Passenger Cars:



The expectations for future attainable CAFE in the current survey are reasonably close to the previous four surveys for Ford, GM and DaimlerChrysler.



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. Although fuel economy is forecast to increase through 2009, it has actually decreased for Japanese manufacturers since 1992 as a result of an increase in average vehicle size.

Light Trucks:

Results of the current survey are in general agreement with those of Delphi VIII and Delphi IX.

STRATEGIC CONSIDERATIONS

CAFE standards cause artificial constraints on domestic and European manufacturers in product mix and pricing, while Japanese manufacturers are little affected. CAFÉ standards impose a disproportional burden on domestic manufacturers that have traditionally built larger cars that customers have demanded. Japanese vehicles are more fuel-efficient than

domestic vehicles primarily because they are smaller. As the Japanese increase average vehicle size to meet domestic customer demand, the gap between Japanese and domestic manufacturers may decrease. Panelists do not forecast a reduction in this gap, however.

A critical competitive point is the fact that the domestic manufacturers have been having difficulty meeting CAFE standards. In fact, they may be borrowing from the future to meet current levels. Japanese manufacturers have been accruing credits for some time. Consequently, in one scenario, Japanese manufacturers could produce larger, less fuel efficient vehicles than their domestic counterparts while still meeting CAFE.

There are many components and systems under development that could significantly alter future fuel-economy levels. Among these are constant velocity transmissions and diesel engines for light trucks. A breakthrough in the control of emissions from diesel engines could measurably alter the future CAFE picture.

See TECH-2 for additional strategic considerations regarding CAFE.

TECH-4 What percentage improvement in fuel economy will come from each of the following sources by 2004 and 2009? Percentage improvement is (mpg increment/current mpg) x 100. Please use the fuel economy of current vehicles as a baseline for all forecasts. Assume a typical gasoline engine vehicle except for energy storage and hybrid powertrain.

SOURCES	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004 (%)	2009 (%)	2004 (%)	2009 (%)
ACCESSORY DRIVES	3	3	2/3	3/5
AERODYNAMICS	2	3	1/3	2/4
DOWNSIZING	3	4	1/3	2/5
ELECTRONIC CONTROLS	3	5	2/5	3/5
ENERGY STORAGE*	5	10	3/5	5/10
ENGINE EFFICIENCY	5	8	3/5	5/10
HYBRID POWERTRAIN*	10	15	5/11	10/20
REDUCED TIRE ROLLING RESISTANCE	2	2	1/ 2	1.5/3
TRANSMISSION FINAL DRIVE EFFICIENCY	3	4	2/3	3/5
WEIGHT REDUCTION WITHOUT DOWNSIZING	3.5	5	2/5	4/8

*For those vehicles using this technology.

OTHER RESPONSES

- 42V electrical system: 2004 5%; 2009 10%
- Alternate fuels/engines: 2004 1%; 2009 5%
- CVT: 2004 2-10% CVT: 2009 4-10% 5-responses
- Drive-by-wire : 2004 0- 4%; 2009 20- 26% 2-responses
- Electric power steering: 2004 1-4%; 2009 2-7% 3-responses
- Electronic speed-controlled fuel pump: 2004 2%; 2009 2%
- Fuel cell : 2009 8%.
- Full length underbody pans: 2004 3%; 2009 7%
- Recovery of waste energy: 2004 2%; 2009 5%
- Starter alternator: 2009 10%
- Wheel Bearings: 2004: 5%; 2009: 5%

SELECTED EDITED COMMENTS

- Hybrids show great promise but deserve time to mature and gain market acceptance. In the meantime, conventional gasoline- and diesel-fueled powertrains have the potential for significant improvements if powertrain engineers can master interactions between fuel efficiency and emission (exhaust and evaporative) performance requirements.
- Accessory drive improvements from going to a high voltage electrical system and using electricity for p/s, a/c, water pump, and oil pump.

- Accessory drive gains will come primarily from conversion from mechanical to individual electrical accessory drives. Waste energy recovery will be in the form of braking energy, coolant and exhaust heat energy, etc. Conversion will be to usable electrical and mechanical energy.
- Automotive accessory efficiency improvement could be the most likely source of mpg increase.
- Engine-and transmission-efficiency improvements will likely play the largest role over the next ten years. While hybrids offer substantial fuel economy improvement, cost and lack of customer "payback" will limit the number of hybrids produced/sold to a relatively small number.
- Higher engine efficiency by more use of superchargers and turbochargers. Also some diesel increase usage if emissions can be accomplished. S/C & T/C allow smaller displacement engines keep the same power output, resulting in substantial fuel economy savings.
- Materials and weight reduction are very highly leveraged methods for fuel economy improvement.
- Vehicle roominess will be improved. It means CDxA (drag coefficient times frontal area) will not be improved, even though CD is improved.
- Considerable gains are theoretically possible with a CVT-optimized powertrain, but the engine people do not appear to be working in this direction that I can see.
- Lack of customer "pull" for fuel economy (in N.A.) will result in manufacturers making only those fuel economy improvements that can be made at relatively low cost with little tradeoff to other "customer attributes." Consequently, not much will happen unless there is a big change in CAFE laws or fuel costs/availability. Customer pull for safety, performance, function, and features is driving weight up, not down.
- More efficient electrical systems will achieve smaller, more efficient electrical components, e.g. combined starter/alternator.
- Significant fuel economy improvements will require some sacrifices (or at least changes in attitude) by the consumer.
- The number of hybrids or electric vehicles in the fleet in 2004 will have no impact on the overall fleet fuel economy.
- There is always a greater expectation for improvements than what car companies provide

RESULTS SUMMARY

Panelists forecast that the largest improvements in fuel economy by 2009 will come from hybrid powertrain (15 percent) and energy storage (10 percent) for vehicles that use these technologies. The largest improvements in currently used vehicle systems are forecast to come from increased engine efficiency. Two panelists forecast that drive-by-wire technology will produce fuel-economy improvements of 20-26 percent by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

SOURCES	MANUFACTURER MEAN	SUPPLIER MEAN
ENERGY STORAGE 2004	5.9	3.8
HYBRID POWERTRAIN 2004	11.4	6.9
ENERGY STORAGE 2009	10	6.9
HYBRID POWERTRAIN 2009	18.1	12

Manufacturers forecast somewhat higher penetrations of energy storage and hybrid powertrain than do suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was asked in this format for the first time in the 1996 Delphi VIII survey for accessory drives, aerodynamics, downsizing, engine efficiency, reduced tire rolling resistance and weight reduction without downsizing. Results for the current survey are in good agreement with the past two surveys for the systems or factors covered.

STRATEGIC CONSIDERATIONS

Although hybrid powertrain was forecast to produce the greatest improvement in fuel economy of the systems noted, the impact on total fleet fuel economy is expected to be small because of the forecast low penetration of such vehicles. (See Tech-6) The same is likely for energy storage systems, although a forecast for future penetration of this system is not covered in this survey.

Panelists forecast that fuel-economy improvements will be obtained through a number of systems or vehicle attributes. No single "silver bullet" is expected to improve fuel economy dramatically in the next decade.

The panelists' forecast for fuel-economy improvement as a result of weight reduction in this question is greater than would be expected for the weight reduction forecast in TECH-26. Panelists forecast a 5 percent reduction in the weight of passenger cars by 2009 in TECH-26. This corresponds to an average weight reduction of about 150 pounds. This weight reduction would be expected to produce an improvement in fuel economy of 0.5 to 0.6 mpg, or about a 2 percent improvement in fuel economy for a vehicle at 28 mpg.

Panelists forecast no decrease in the weight of light trucks (TECH-26), and no associated fuel-economy gain would be expected.

Reduction of vehicle weight can be accomplished by either making the vehicle smaller or reducing the weight of a fixed-size vehicle. The vehicle can also be made smaller by redesign. On a fleet basis, however, the average vehicle can be made smaller by changing the vehicle mix. This means selling more small vehicles and fewer large vehicles. This can happen rapidly, as was seen during the gasoline shortages of the late 1970s. Manufacturers and suppliers must have some flexibility in shifting manufacturing facilities from large

vehicles to small vehicles to prepare for such an eventuality. If manufacturers are not able to meet CAFE standards, they may have to resort to forcing the market to smaller cars through pricing. This may be a difficult scenario if some competing manufacturers do not have problems meeting CAFE standards and are, therefore, able to maintain the price of their larger vehicles.

Vehicle weight reduction can also be accomplished by redesign of systems and components or material substitutions. Math-based engineering offers the potential for significant weight reduction by optimizing component design. Material substitution is a costly method of weight reduction, but is being pursued aggressively on some major components such as engine cylinder blocks and cylinder heads. Reducing the weight of a major component such as an engine can have compounding effects that can spread throughout the vehicle. The Japanese have led the way in this approach to total vehicle weight reduction, which has contributed to improved fuel economy. The Japanese manufacturers have also historically sold smaller vehicles than the domestic manufacturers. This is changing, however, as Japanese manufacturers upsize their vehicles to meet the demands of the North American marketplace.

The panelist responses regarding other potential areas for fuel economy improvement should also be noted, as they may include areas that could become a source for competitive advantage.

TECH-5 Can the PNGV (Partnership for a New Generation of Vehicles) goal of 80 mpg be achieved in a production, family-sized (five passenger) car? If yes, by what year?

YES	NO	MEDIAN RESPONSE	INTERQUARTILE RANGE
		IF YES, BY WHAT YEAR?	IF YES, BY WHAT YEAR?
52.7%	47.3%	Year: 2010	Year: 2006/2010

SELECTED EDITED COMMENTS

Cost

- Affordability is the only issue.
- Can it?" Will it? No. The reason being cost and lack of "customer value."
- It is not at a practical price before 2020.
- Not with vehicle size and economic targets.
- Technical feasibility has been pushed back five to six years by new LEV II and tier 2 emissions standards. Costs will be too high for commercial viability of significant numbers of vehicles, unless the cost of fuel is at European levels.
- The targets, except for cost, will be met with a low volume, high cost vehicle. The PNGV cost targets for cost will not be met.
- Too much money and time is being wasted on dead-end technologies.

Hybrid

- Assumes a CIDI diesel engine in a hybrid vehicle weighing less than 2000 lbs.
- Build on hybrid introduced by Toyota. Honda - 65 mpg, 4 passenger car.
- Hybrid vehicle required.
- Need fuel cell or hybrid.

Market acceptance

- No. The market is not accepting. It does not have value.
- No way, no how, no time. And why do it when gas is approximately $1 per gallon?
- The vehicle would probably not be saleable. An example is GM Metro XFI which gave CAFE of 65 mpg but was not accepted in the marketplace. Prospective owners would need major incentives to purchase. Acceleration performance would be poor due to small engine usage required for such high CAFE.
- Who would buy it? There are no silver bullet technologies in PNGV and, therefore, the people buying passenger vehicles are not going to be interested in an ultralight weight vehicle with an exotic powerplant and poor performance. PNGV would be a more useful investment of taxpayers dollars if organizations and individuals with special agendas were omitted from the effort.

Other

- Cannot develop "production" capability.
- Depends on safety requirements.
- Determining factors involve continued and more stringent control of oil production by OPEC and the next century's technologies and regulations.
- Fuel tax increase and legislation is required to change manufacturer and customer expectations on performance, annual fuel expense.
- Many other things have to happen, such as safety, legislation, social-economic situation, etc.
- No. Not unless engines and weight-added options are severely restricted.
- Technologies developed as a result of PNGV effort will show up in other products.

RESULTS SUMMARY

More than half of panelists say that the PNGV goal of 80 mpg can be achieved. The median forecast year for achievement is 2010.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was first asked in its current form in Delphi IX. The percentage of respondents forecasting that the 80 mpg goal could be achieved were similar between the two forecasts. The median response for year of achievement of the goal was 2015 in Delphi IX compared with 2010 in the current survey.

STRATEGIC CONSIDERATIONS

A five-passenger vehicle attaining a fuel economy of 80 mpg will not be a result of continuous improvement of current systems. It will require the development and applications of new technology, particularly improved powertrains, and total mass reduction. The technology may be available today to attain the fuel economy goal, but not at a cost that is competitive with current vehicles. Two powertrain candidates that show considerable potential are diesel/electric hybrids and fuel cells. Significant challenges face each of these candidates, however. These challenges are elaborated in TECH-6. These powertrain candidates will likely require the application of other vehicle- system revisions such as aluminum bodies, low-rolling-resistance tires, etc.

The high-volume use of these alternative systems has obvious strategic implications for current suppliers. If and when this transition takes place, electric motors could replace transmissions, aluminum could replace steel, and much more. Suppliers must keep abreast of developments in this area in order to anticipate threats to current products and identify new business opportunities.

TECH-6 What percentage of North American-produced passenger cars and light trucks will use each of the following fuels or power plants in 2004 and 2009? Please include fleets in your estimate.

PASSENGER CARS	1998* (%)	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004 (%)	2009 (%)	2004 (%)	2009 (%)
FUELS					
ALCOHOL OR ALCOHOL/GASOLINE (>10 PERCENT ALCOHOL; INCLUDES FLEX FUEL OR VARIABLE FUEL)	<1	1	2.1	1/3	1/5
NATURAL GAS	0	1	1	0/1	0/3
PROPANE	0	0	0	0/1	0/1.8
POWER PLANTS					
DIESEL	0.2	1	2	0.3/2	0.7/5
ELECTRIC	0	0.1	1	0/1	0/2
FUEL CELLS	0	0	1	0/1	0.2/3
HYBRID-ELECTRIC/COMBUSTION ENGINE	0	1	3	0.2/2	1/5

LIGHT TRUCKS	1998* (%)	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004 (%)	2009 (%)	2004 (%)	2009 (%)
FUELS					
ALCOHOL OR ALCOHOL/GASOLINE (>10 PERCENT ALCOHOL; INCLUDES FLEX FUEL OR VARIABLE FUEL)	<1	1	2	1/2	1/5
NATURAL GAS	0	0.9	1	0/2	0/4
PROPANE	0	0	0	0/1	0/2
POWER PLANTS					
DIESEL	1.6	3	5	2/5	3/10
ELECTRIC	0	0	0	0/0.1	0/1
FUEL CELLS	0	0	1	0/0	0/2
HYBRID-ELECTRIC/COMBUSTION ENGINE	0	0.5	1	0/1	0/5

*Source: Ward's Automotive Reports, Dec. 21, 1998, Jan. 25, 1999, and OSAT estimates. Rates for 1998 are based on production in U.S., Canada, and Mexico for the U.S. market.

OTHER RESPONSES

- Direct injection SI. Passenger cars 2004: 0%; 2009: 15%; light trucks 2004: 1%; 2009: 10%
- Engine driven supercharger or turbocharger going the way of Europe to get more power out of the engine for fuel economy benefit as driven by much higher gas prices. The percent depends a great deal on gasoline prices in the U.S. Passenger cars 2004: 10%; 2009: 20%; light trucks 2004: 10%; 2009: 20%
- Gasoline. Passenger cars 2004: 95%; 2009: 83%; light trucks 2004: 90%; 2009: 70%

SELECTED EDITED COMMENTS

- California emission standards (NOx) will likely influence federal emissions standards and could make the diesel engine a nonviable alternative in spite of its lower fuel consumption. Low sulfur fuels will become mainstream (emissions/emissions hardware computability).
- Cost and infrastructure support is the issue.
- The combined economic, environmental, and energy advantages of nongasoline and nondiesel powerplants will limit market penetrations to only about 10 percent in the next 30 years. Automakers will continue to improve gasoline and diesel-burning engines to reduce emissions and improve fuel economy.
- With gas prices so low, there is no incentive for consumers to buy efficient vehicles much less have to worry about the availability of alternative fuels.

RESULTS SUMMARY

Gasoline-fueled, internal-combustion engines are forecast to remain the predominant power plants through 2009. All other fuels or power plants are forecast to have penetrations of less than 3 percent for passenger cars and 5 percent for light trucks.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following tables.

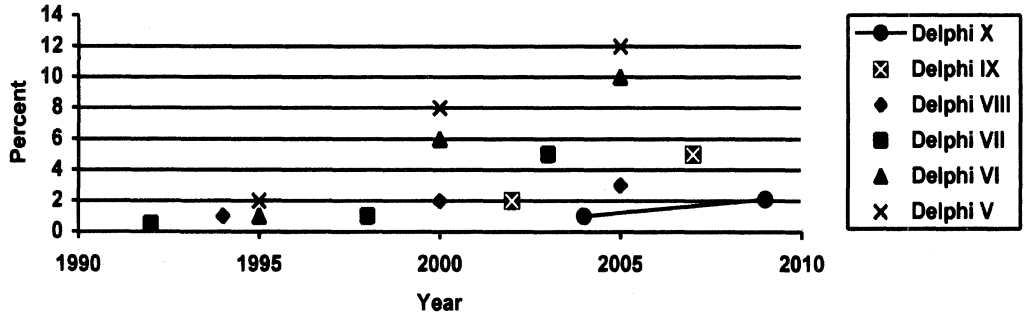
PASSENGER CARS	MANUFACTURER MEAN	SUPPLIER MEAN
POWER PLANTS		
DIESEL 2004	2.9	1.3
DIESEL 2009	6.2	2.9
LIGHT TRUCKS	MANUFACTURER MEAN	SUPPLIER MEAN
POWER PLANTS		
ALCOHOL 2004	2.6	1.3
DIESEL 2004	5.4	3.4
HYBRID-ELECTRIC/COMBUSTION ENGINE 2009	5.4	1.9

Manufacturers forecast a higher application of diesel engines in passenger cars in 2004 and 2009. In light trucks, manufacturers forecast higher application of alcohol and diesel in 2004 and hybrids in 2009.

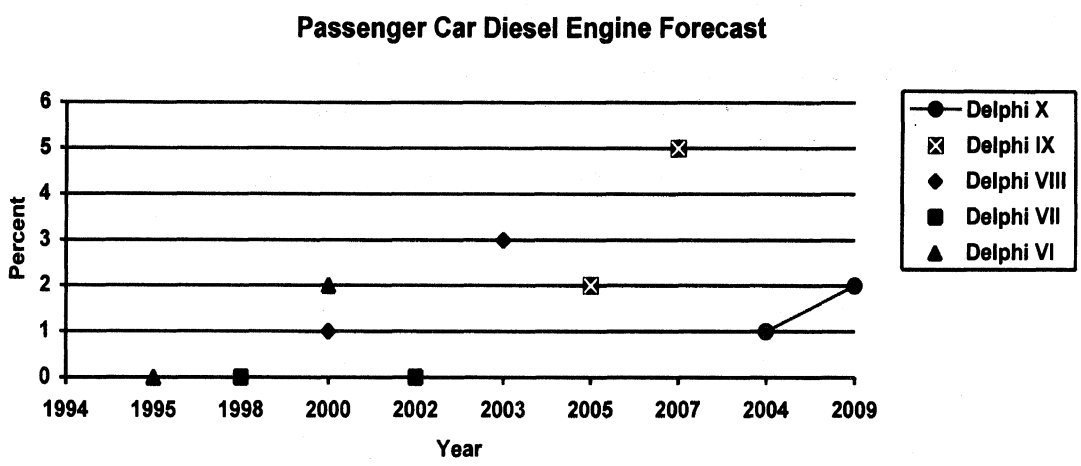
TREND FROM PREVIOUS DELPHI SURVEYS

The forecast use of alcohol in passenger cars has decreased with each new survey, as shown in the following graph.

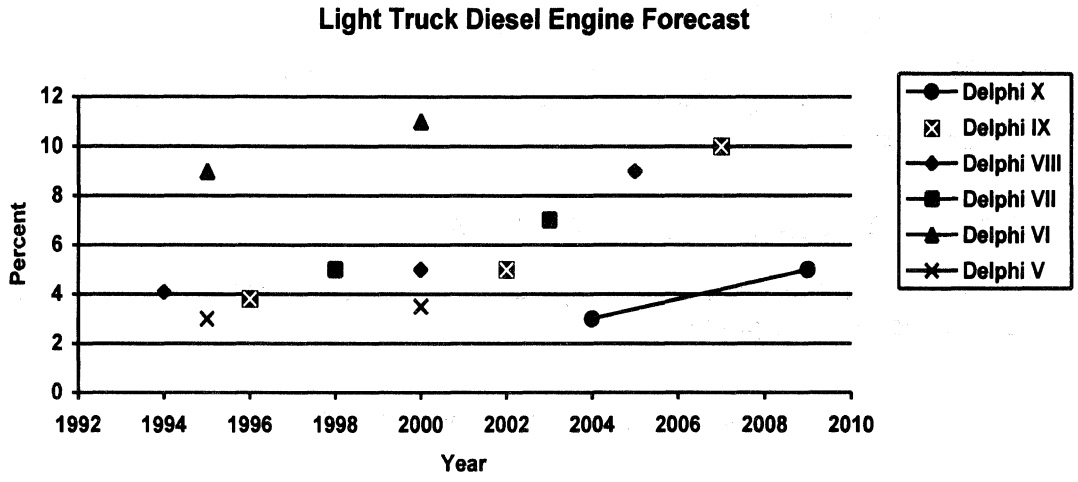
Passenger Car Alcohol or Alcohol/Gasoline Use Forecasts



Forecasts for diesel engine use in passenger cars is summarized in the following graph. The current forecast is below the previous forecast.



The current forecast for diesel engines in light-duty trucks is below that of previous forecasts, as shown in the following graph. This is likely a result of anticipated difficulty meeting emissions standards.



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

STRATEGIC CONSIDERATIONS

Significant changes in fuel or power plants would have a major impact on infrastructure and suppliers of engines, transmissions, and related components. Panelists do not foresee major change in this area in the next decade. It is important for suppliers to closely monitor this issue, however, as there is a significant amount of research and development devoted to alternative fuels and power plants, and breakthroughs are difficult to predict.

There is much in the literature regarding the introduction of hybrid-electric vehicles and the possible introduction of fuel-cell-powered vehicles in the next five years. These two highly touted alternatives have numerous roadblocks to high-volume production.

Hybrid-electric vehicles face serious challenges in the areas of cost and battery life. Fuel-cell-powered vehicles have a major infrastructure problem if they are to be powered by hydrogen, and they face increased cost and reduced efficiency if on-board reformers are to be used. Also, the fuel cell requires significant invention. Breakthroughs in any of these

areas could drastically change the forecast for future application. An electric drivetrain is common to the electric-hybrid and fuel-cell vehicles. Much remains to be done before this drivetrain can compete economically; however, progress is being made.

Diesel engines offer the potential for significant fuel-economy improvements, but increasingly stringent emissions standards make meaningful application of this alternative power plant questionable. Furthermore, at the current, and forecast, price of gasoline, there is not great incentive to use a power plant that has some disadvantages compared with gasoline-powered engines. These disadvantages include engine cost, engine noise, odor of fuel and exhaust, reduced power, and increased weight, and difficulty starting in cold climates. Diesel engines are widely used in Europe and Japan where fuel costs are three to four times those of the U.S. New, high-tech diesels are vastly improved over their predecessors in most important attributes. Still, nitrogen oxide and particulate emissions remain very challenging problems.

Alternative fuels such as natural gas and propane offer reduced emissions, but decreased vehicle range and limited infrastructure for distribution will limit future use as long as gasoline is available and inexpensive.

The forecast for use of alcohol or alcohol/gasoline fuels has decreased steadily in the last decade. Again, readily available and inexpensive gasoline is a fuel that is difficult to displace. Furthermore, some of the emission benefits of the alcohols are now suspect as are the economies of alcohol fuel production.

See TECH-5 for further discussion on these subjects.

TECH-7 What percentage of electric or hybrid passenger cars will utilize the following battery types in 2004 and 2009?

TYPES OF BATTERIES	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004	2009	2004	2009
LEAD-ACID	50	30	40/60	15/40
LITHIUM ION	10	15	5/10.3	10/15
LITHIUM-POLYMER	7	14.5	5/10	10/20
NICKEL-CADMIUM	5	5	5/10	2.8/10
NICKEL-METAL HYDRIDE	25	30	18.8/30	20/37
ZINC-AIR	2	5	1/5	2/6.3

ROUND 2 OTHER RESPONSES

- Chemical osmotic: 2004 4%; 2009 6%
- Fuel cell: 2009 50%
- PEM: 2004 5%; 2009 30%
- Ultra- and Pseudo-capacitors: 2004 1%; 2009 25%

SELECTED EDITED COMMENTS

- Battery production is the biggest unknown.
- Hybrid powerplants have made advances with the introduction of starter-flywheel technologies, and need higher performance energy storage.
- Lead-acid does not meet "customer requirements" for electric cars. Lithium-polymer looks very promising for hybrid applications.
- These are a somewhat skeptical outlook based on the last 25 years of development work in this field, particularly with respect to cost. Virtually all the usage of nonlead/acid-type batteries is subsidized and has shown few signs of competing in the marketplace.
- This question should not be confined to electric and hybrid vehicles. Conventional vehicles may also utilize alternative battery technology in this timeframe.
- Inherently difficult to predict battery technology.
- Lead-acid is too heavy, stores too little energy, and takes up too much space. Assuming hybrids and electric vehicles will remain relative low volume "niche" vehicles, cost diminishes in importance as customer/manufacturer is paying a premium for this type of vehicle. Consequently, there is pull to use "best" battery technology available.
- Percentage is difficult to pick. Nickel metal hybrids will be higher due to better efficiency and increasing accessory use.
- Some vehicles, particularly hybrids, may employ more than one battery/capacitor technology. Capacitors may be needed for efficient brake energy recovery. L-ion and L-polymer may well be used in all vehicles that have significant telematics suites, to support the electronics when the vehicle is "off." These batteries may be too expensive or a potential liability issue for tractive power packs. Zinc-air's infrastructure requirements may well doom it, aside from very specialized applications. Environmental disposal concerns will constrain unlimited use of ni-cads.

- The long term drivers for electric cars leaves their future seriously in doubt. For hybrids sold in the same manner as regular vehicles, the future of anything but the cheapest battery, i.e., lead-acid, is likewise doubtful.
- The percentages given include alternator-starter vehicles with regenerative braking energy and some propulsion assist capability.
- Unless something dramatic happens, hybrids and electrics will only be novelty vehicles for a long time to come.

RESULTS SUMMARY

Panelists forecast that lead-acid batteries will be used in most (50 percent) electric or hybrid vehicles through 2004, but other alternatives such as nickel-metal hydride, lithium-ion, and lithium-polymer will see increased use by 2009.

MANUFACTURER/SUPPLIER COMPARISON

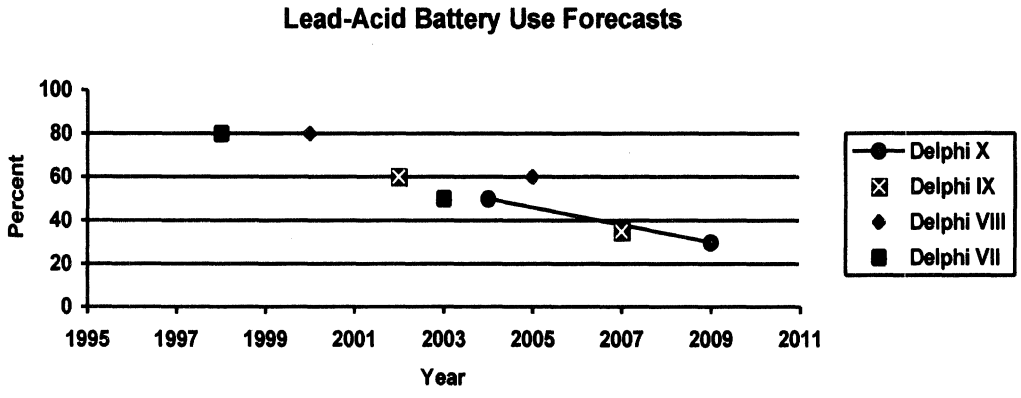
There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

TYPES OF BATTERIES	MANUFACTURER MEAN	SUPPLIER MEAN
NICKEL-CADMIUM 2004	5.2	9.1
NICKEL-METAL HYDRIDE 2004	32.9	19.5
NICKEL-CADMIUM 2009	4	8

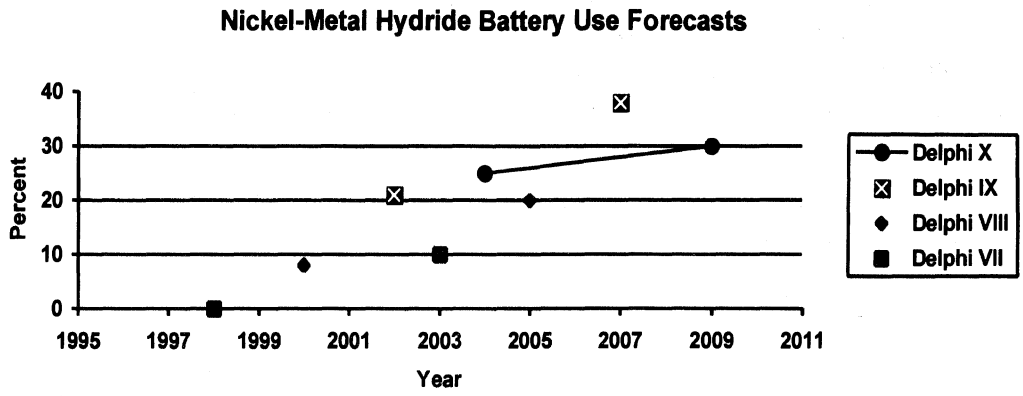
Manufacturers forecast higher use of nickel-metal hydride batteries in 2004 than do suppliers. Manufacturers forecast lower use of nickel-cadmium batteries in both 2004 and 2009 than do suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

The forecasts for lead-acid and nickel-metal hydride are summarized in the following graphs.



The current forecast for lead-acid batteries is in close agreement with past forecasts.



The current forecast for nickel-metal hydride batteries is in general agreement with past forecasts, with the long range forecast on the low side of past forecasts.

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. However, cost remains a problem for both of these alternatives. 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.

Without a breakthrough in the area of battery cost and energy density, the all-electric vehicle will see very limited application. Only subsidy of these vehicles by manufacturers or the government will change this outlook. Hybrid vehicles are in a similar position regarding battery cost, but energy density is less of an issue.

TECH-8 What percentage of passenger cars with hybrid electric/combustion engine propulsion will utilize the following types of combustion engines in 2004 and 2009?

COMBUSTION ENGINE USED IN HYBRID VEHICLES				
COMBUSTION ENGINE	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004	2009	2004	2009
COMPRESSION IGNITION, DIESEL	25	30	15/50	20/60
GAS TURBINE	0	3	0/8	0/20
SPARK IGNITION	70	50	45/80	30/72.5
STIRLING	0	0	0/0	0/4.3

OTHER RESPONSES

- Fuel Cell 2004: 50%; 2009 50%
- Fuel Cell 2004: 0%; 2009: 25%
- Fuel Cell 2004: 0%; 2009: 1%

SELECTED EDITED COMMENTS

- Cost will keep turbines and stirlings off the roads.
- Future NOx standards will likely preclude the diesel engine from car and light truck applications (at least in California).
- Gas turbine is dependent on CVT and other powertrain technology.
- The cost penalty of having two powerplants means that both must be affordable. The gas turbine has lagged behind gasoline engines but shows the most promise in affordable sequential hybrids, i.e., mechanical power to electrical power to power at the wheels.
- This depends on legal and competitive environments.

RESULTS SUMMARY

Panelists forecast that spark ignition engines will be used in the majority of hybrid vehicles in the next decade. Diesel-engine use is expected to increase to 30 percent by 2009.

MANUFACTURER/SUPPLIER COMPARISON

The statistically significant differences in responses between manufacturers and suppliers are shown in the following tables.

COMBUSTION ENGINE USED IN HYBRID VEHICLES		
COMBUSTION ENGINE	MANUFACTURER MEAN	SUPPLIER MEAN
GAS TURBINE 2004	0.9	5
GAS TURBINE 2009	3.9	5
SPARK IGNITION 2004	69.9	60
SPARK IGNITION 2009	58.4	40

Manufacturers forecast a lesser use of gas turbines in 2004 and 2009 than do suppliers. Manufacturers forecast a greater use of spark ignited engines in 2004 and 2009 than do suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was first asked in the 1998 forecast Delphi IX. Results from the two forecasts are very similar.

STRATEGIC CONSIDERATIONS

There is a large spread in the interquartile range for diesel, gas turbine and spark-ignited engines. This indicates uncertainty or, perhaps, multiple strategies within the industry.

Panelist comments reflect the challenges for engines other than gasoline engines. Breakthroughs in technology could alter the outlook for these alternatives. There is considerable effort being expended within the industry in this area, including substantial work within the PNGV program.

Also see TECH-6 for additional issues affecting alternative power plants.

TECH-9 Can vehicles with an electric drivetrain reach cost parity with gasoline-engine automatic-transmission-powered vehicles? If yes, by what year?

YES	NO	MEDIAN RESPONSE BY WHAT YEAR?	INTERQUARTILE RANGE BY WHAT YEAR?
47.1	52.9	2015	2015/2020

SELECTED EDITED COMMENTS

No: (11 responses)

- A breakthrough is needed to get equivalent cost for equivalent life and performance.
- Battery technology (cost, mass, energy, storage, capacity, life) is roadblock number one.
- Battery technology is the key enabler for mileage parity but cost is at issue. Fuel cells are the long-term answer.
- Batteries will not make it. Cost of manufacture, durability and disposal will need to be subsidized. Fuel cells are the best chance of making cost parity.
- Electric machinery is $1.50/lb. Automatic transmissions with similar capability are of less cost.
- I believe anything is possible, but it would take a major refocusing of the auto industry to back electric vehicles, and I don't see that happening in the near future. There is so much momentum behind the gasoline engine, and they are improving all the time, that the bar keeps getting raised higher for electrics to compete.
- I don't believe cost of powertrains will ever reach parity. Electric engines will only grow due to cost of fuel or CAFE issues.
- Major breakthroughs in permanent magnet field strengths are the enabling technology here. Another jump in strength like that achieved with the Ni-FE material at low cost could achieve cost parity with conventional drivetrains, but I do not see this happening.
- Not unless there is a major breakthrough in battery technology. This seems even less likely now, with efforts going more towards development of hybrid electric vehicles and fuel-cell technology and fuel-cell vehicles.
- The physics of this problem are very simple. Torque from an electric motor is I(current) x B(magnetic flux). You have to be able to store enough power to get customer-acceptable levels of torque for a given vehicle. If you can't store enough power in a weight/volume package comparable to a gas tank, which will require a battery breakthrough that does not appear to be coming, you will never have enough I (current) for some portion of the drive cycle. Without enough I, you must have significantly more B (magnetic flux) to compensate. Given present technology, you need almost an order of magnitude more. That kind of breakthrough is just not on the horizon. The last breakthrough in B roughly tripled flux density.
- This can only happen if petroleum supply dries up or government taxes are applied to petroleum-based fuels to force equivalency. In a free market with adequate supply, it can never happen.

Yes: (8 responses)

- Electric drivetrains with fuel cells as the power source have the potential to have cost parity with conventional powertrains. Strategic commitment, volume manufacturing investment, and key design breakthroughs are needed for this to be achieved.

- Electronic controls and actuators will do what automatic transmission can do with less weight. Manufacturing cost will be on par with current automatic transmissions 5 years after product feasibility.
- Fuel cells and electric powertrains have the potential to reach cost parity with conventional powertrains. Major work on manufacturing processes and commitment to high volume will be needed to achieve this potential. This parity will be only for selective applications by 2010 and will require volume commitments in the 2005 to 2007 timeframe.
- Infrastructures to gain economies of scale are required.
- Lots of time required to get over paradigm.
- When sufficient volumes drive new manufacturing processes.
- Power-electronic-controller cost will come down with demand and volume. This will be a chicken-and-egg issue. Demand for electronics supplier won't be reached until volume is high, and volume won't happen until price is low enough, barring government legislation forcing HEV technology.
- That would require agreement that total costs (air pollution, fuel, maintenance) make a pure electric drivetrain more appealing. This could occur if the energy density and costs of battery technology improve and/or the future course of fuel-cell technology and its fueling infrastructure becomes more focused. I think the future for hybrid gasoline/electric powertrains to reach parity with conventional gasoline drivetrains looks bright.
- This can be achieved through joint development of fuel-cell technology.

Other:

- Power controller cost is a key issue.
- These powertrains will only be driven by external governmental factors. Fuel price, emission fines, etc.
- Three words: batteries, batteries, batteries.
- The vehicle to be concerned with is a starter/alternator vehicle. The starter/alternator can replace the auto transmission as well as provide the electrical power for the vehicle, A/C systems, P/S (electric), as well as electric brakes. This needs a systems/holistic study.

RESULTS SUMMARY

Panelists are nearly evenly divided regarding the potential of an electric drivetrain to reach cost parity with a gasoline-engine automatic-transmission-powered vehicle. For those that forecast future cost parity, the median year for achievement is 2015.

MANUFACTURER/SUPPLIER COMPARISON

There is a statistically significant difference in responses between manufacturers and suppliers. These differences are summarized in the following table.

	MANUFACTURER YES	SUPPLIER YES
CAN DRIVETRAINS REACH COST PARITY	26.9%	62.2%

Suppliers are much more optimistic regarding the potential of vehicles with an electric drivetrain reaching cost parity with gasoline-engine automatic-transmission-powered vehicles than are manufacturers. This is an interesting finding. It may be that suppliers are focused on individual components, while manufacturers consider the whole vehicle. It is possible that

suppliers are not aware of challenges across all components of the vehicles, as are the manufacturers, or that suppliers have more detailed information on components. It is also possible that manufacturers' responses are influenced by investment in current systems and components.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in this format in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

Cost is one of the major deterrents to high-volume sales of electric vehicles. About half of the panelists forecast that this cannot be corrected in the future.

A number of panelists focus on fuel cells as having the greatest potential to compete in the area of cost. In spite of the optimism regarding fuel cells, panelists do not forecast significant use in the next decade. (See TECH-6)

This area must be watched closely, because breakthroughs in technology could have far-reaching impacts on the industry.

If, in fact, the electric drivetrain reaches cost parity with the current drivetrain (transmission and final drive), a major shift to a hybrid electric vehicle could occur. Clearly, invention is still required but progress has been quite significant in recent years.

Suppliers may be at some risk by investing in components that will never be used in large numbers.

Manufacturers may be at risk of missing a breakthrough that will change the industry.

TECH-10 What are the greatest challenges of developing hybrid powertrains?

SELECTED EDITED COMMENTS

- A legitimate driver, the gains reported so far with the Prius are pretty puny. They may appeal from a CAFE standpoint, but they will probably have to be legislated to gain wide-scale acceptance. 2) Reliability, a function of part count; and hybrids have more parts. 3) NVH. Yes, you can hear the engine start back up. You can hear the electric drive above the engine under some conditions. No big deal for a compact the size of the Prius, but the number of people willing to pay extra for a noisier car is limited.
- Challenges include the price of gasoline, performance, reliability, durability, serviceability, safety, and technology development (e.g., controls).
- Complexity of systems; still need a good, high-capacity battery; quick charges; long life; reasonable cost; if diesel powered, it needs to meet emissions standards.
- Consumer acceptance, performance, reliability.
- Cost and durability, as well as reliability, that match current gasoline engine-based powertrains.
- Cost is an issue. You basically need two powertrains. Trailer new/mountain grade capability is also an issue.
- Cost is challenge number one, followed by a lack of individual consumer economic incentive to own a hybrid vehicle. Why bother when gas cost is $1.20 per gallon?
- Cost is the greatest challenge for hybrids. In general, the needed equipment is a cost add with no chance to be cost competitive with equivalent conventional powertrains. Added features and fuel economy can add only limited value to offset the added cost.
- Cost, energy storage, and application to light trucks and SUVs.
- Cost. Controllability is no longer an issue (Toyota Prius). Remember it is COST! COST! COST! in the automotive business.
- Customer acceptance (due to diminished vehicle performance and passenger comfort), infrastructure, emissions, overall costs.
- Delivering the power and convenience the U.S. market has come to expect from its vehicles.
- Developing the infrastructure to support them. Beyond the need for fueling systems, the complexity will require service capabilities far greater than anything in use today.
- Duty cycle comparable to contemporary distance divided by time; and durability comparable to contemporary distance divided by time.
- Efficiency losses - mechanical to electrical and back again.
- Establish an economic pull.
- Field service.
- Finding enough space to house the two systems required.
- It will only happen when the cost of liquid hydrocarbon fuel makes the cost of driving electric vehicles substantially cheaper.
- Keeping the customer from realizing that the powertrain is transitioning from one power source to another, and bringing the total cost of ownership in line with conventional powertrains.
- Mechanical shifting designs. Use of continuous variable transmission.
- Reducing complexity. Assuring safety. Achieving feasible cost.
- Starting IC engines following stop or low-speed urban driving as vehicle age increases.

- Systems integration.
- Technical acceptance by the public. Technologies which have the reliability and cost of current technologies. The price of gasoline.
- The cost of two powertrains are not overcome by fuel savings. Providing acceptable performance for the driver and still trying to save fuel consumption.
- The development of a national infrastructure to produce systems and component parts for hybrid powertrains.
- The price and range in electric traction.

RESULTS SUMMARY

Panelists responses are summarized in the following table.

CHALLENGE	NUMBER OF RESPONSES
COST	37
RELIABILITY	9
BATTERIES	10
CUSTOMER ACCEPTANCE	8
PERFORMANCE/ACCELERATION	7
PACKAGING/SPACE	6
CONTROLS	5
COMPLEXITY	4
PRICE OF GASOLINE	3
WEIGHT	2
SERVICE	2
SAFETY	2
NOISE	2
DRIVEABILITY	2

Additional miscellaneous challenges are listed below.

- Range.
- OBDII.
- Starting IC engines following stop or low speed urban driving as vehicle age increases
- Delivering the power and convenience the U.S. market has come to expect from its vehicles.
- Efficiency losses - mechanical to electrical and back again.
- Mechanical shifting designs. Use of continuous variable transmission.
- Investment.
- Systems integration.
- The development of a National infrastructure to produce systems and component parts for hybrid powertrains.
- If diesel powered, it needs to meet emissions standards.
- Impact on supply channels
- Establish an economic pull.

- Application to light trucks and SUV's.
- Vehicle dynamics.

MANUFACTURER/SUPPLIER COMPARISON

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

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi survey.

STRATEGIC CONSIDERATIONS

High-volume sales of hybrid vehicles would have a major impact on the automotive industry. They would create a new market for electric motors and associated controls. As evidenced by the responses to this question, however, many challenges face vehicles powered by hybrid powertrains.

Toyota and Honda will market hybrid vehicles in Japan and the United States. This does not mean, however, that the issues noted by the Delphi panelists have been resolved. For example, the price of each vehicle is widely reported to be heavily subsidized by the manufacturer.

Cost is the most frequently noted challenge to this product. It is difficult to see how a vehicle that has both an internal combustion engine and an electric drive system and the necessary controls to switch smoothly between the two will ever be cost competitive with a vehicle powered by a gasoline engine. It is likely that government legislation or incentives will be required to allow large-scale sales of hybrid vehicles. The automobile industry's experience with electric vehicles provides some insight into the difficulty of introducing a new concept into a mass market. The hybrid vehicle will not have the range limitations of an electric vehicle, but the cost issue is very real.

Battery life is another major challenge. It is one thing to replace the battery in a conventional vehicle every four years or so. It is quite another thing to replace a sizable battery pack at the same frequency. Also, the battery itself is a significant factor because of cost, size, and weight considerations. With a large battery, one could drive considerable distances as a pure EV and even charge the battery from the electrical grid, thereby, reducing energy costs. A similar battery is obviously less expensive but could negate some of the expected hybrid advantages.

Increased complexity is also a significant consideration. A dual-power-plant vehicle with its associated controls will have many more potential failure modes than a conventional vehicle. Vehicles will have to demonstrate their reliability for some time before the general public will consider purchase.

The increased fuel economy associated with hybrid vehicles will be a difficult sell with gasoline priced as low as forecast for the next decade. Considerable invention is still required to achieve necessary objectives. However, considerable progress is being made; and one should not be surprised if the economic problems respond to engineering ingenuity.

TECH-11 What voltage will be used in 2004 and 2009 to drive the electric motor in electric and gasoline-hybrid electric vehicles? (This value is NOT the system voltage but only the voltage used to drive the electric motor).

DRIVE SYSTEM	VOLTAGE			
	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004	2009	2004	2009
ELECTRIC	220	220	220/220	220/235
GASOLINE/ELECTRIC	42	60	42/115	42/220

SELECTED EDITED COMMENTS

- Higher voltage electric systems will be gaining momentum in the "out years."
- Will probably vary across manufacturers.
- Gasoline vehicles with alternator-starters to recover energy and do launch assist are considered hybrid vehicles. Initially they will use relatively low voltages, but will migrate to higher voltages as drive systems are standardized.
- The same voltage on both pure electrics and hybrids will permit standardization of motors, drives, etc.

RESULTS SUMMARY

Panelists forecast that all-electric vehicles will use 220 volts to drive the electric motor in 2004 and 2009. Hybrid vehicles are forecast to use lower voltage of approximately 60 volts in 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers, with the exception of the item shown in the following table.

DRIVE SYSTEM	MANUFACTURER MEAN	SUPPLIER MEAN
ELECTRIC 2004	229.6	189.6

Manufacturers forecast a somewhat higher voltage to drive the motor of an electric vehicle in 2004 than do suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Forecast

STRATEGIC CONSIDERATIONS

The interquartile range is quite narrow for the voltage to drive the motor in an all-electric vehicle. On the other hand, there is a wide spread in the interquartile range for the voltage used in a gasoline/electric vehicle. This indicates uncertainty or different approaches between manufacturers. One panelist commented that the voltage will probably vary across manufacturers, whereas two panelists noted that voltage will be standardized.

If hybrid-vehicle sales volume become high, it is possible that the voltage used on these vehicles will carry over to gasoline-engine-powered vehicles also. There is incentive to raise the vehicle system voltage in order to improve efficiency and reduce alternator size and weight. The application of a system voltage other than 12 volts to hybrid vehicles may lead to widespread development and tooling of components that are compatible with these higher voltages. See TECH-55 for additional discussion on this issue.

It is possible the respondents interpreted hybrid in two different ways: one using essentially an electric-vehicle drivetrain with higher voltage; the other, more of an gasoline-engine-powered vehicle with an electric-motor assist that uses lower system voltage. As hybrids begin to appear, it will be interesting to track the system voltage of the various designs.

TECH-12 Please indicate your view of the trends in United States federal regulations and legislation over the short term (2000 to 2004) and long term (2005 to 2009). Also, please identify any likely additional areas of legislative and/or regulatory activity.

SCALE →	1	3	5
	MUCH MORE RESTRICTIVE	NO CHANGE	MUCH LESS RESTRICTIVE

LEGISLATION/REGULATORY ACTIVITY	SHORT TERM 2000-2004	LONG TERM 2005-2009
	MEAN RESPONSE	MEAN RESPONSE
ALTERNATE FUEL/POWER SOURCE		
PASSENGER CAR	2.8	2.3*
LIGHT TRUCK	2.7	2.3*
OCCUPANT RESTRAINT/INTERIOR SAFETY		
PASSENGER CAR	2.2	2.0*
LIGHT TRUCK	2.1	2.0*
PRODUCT LIABILITY		
PASSENGER CAR	2.6	2.4*
LIGHT TRUCK	2.6	2.4*
REGIONALIZATION OF NAT'L STANDARDS		
PASSENGER CAR	2.7	2.4*
LIGHT TRUCK	2.7	2.4*
VEHICLE EMISSION STANDARDS		
PASSENGER CAR	2	1.6*
LIGHT TRUCK	1.8	1.4*
VEHICLE INTEGRITY/CRASHWORTHINESS		
PASSENGER CAR	2.2	1.9*
LIGHT TRUCK	2.2	1.9*

*Indicates significant difference in current/2002 comparison.

OTHER RESPONSES

- Controlled operations prevent driving while under the influence, radar braking, automatic control roads/intersections.
- Dynamic stability. Passenger car 2004: 3; 2009: 2; light truck 2004: 3; 2009: 2
- Electric vehicle ID and interrogation. Passenger car 2004: 2; 2009: 1; light truck 2004: 2; 2009: 1
- Electronic emissions. Passenger car 2004: 2; 2009: 1; light truck 2004: 2; 2009: 1
- EMI passenger car 2004: 3; 2009: 2; light truck 2004: 2; 2009: 1
- End-of-life disposal. Passenger car 2004: 3; 2009: 2; light truck 2004: 3; 2009: 2

- For light trucks: accident damage to other vehicles. For passenger and light trucks: pedestrian safety.
- Global normalization. Passenger car 2004: 4; 2009: 5; light truck 2004: 4; 2009: 5
- Local content. Passenger car 2004: 3; 2009: 2; light truck 2004: 3; 2009: 2
- Pass-by noise abatement passenger car 2004: 3; 2009: 2; light truck 2004: 3; 2009: 2
- User taxes. Passenger car 2004: 2; 2009: 1; light truck 2004: 1; 2009: 1
- Vehicle-to-vehicle. Passenger car 2004: 3; 2009: 2; light truck 2004: 3; 2009: 2

SELECTED EDITED COMMENTS

- CO2 emissions.
- Light trucks are likely to be treated more like passenger cars considering probable/most likely vehicle usage. This will, in effect, increase the standards without a numerical change in the CAFÉ requirements.
- Restrictions on where a vehicle can be used (downtown, wilderness) will be restrained, along with some limits on older vehicles; tighter testing.
- This will depend on the political mood in Washington and the economy in general.
- There will be more regionalization of standards, such as California - ZEV or LEV.
- We will be more green.

RESULTS SUMMARY

In the short term (2000 to 2004), panelists forecast more restrictive standards for both passenger cars and light trucks in the areas of vehicle emissions, occupant restraint/interior safety and vehicle integrity/crashworthiness. Little or no change is forecast in the areas of alternate fuel/power source, product liability and regionalization of national standards.

In the long term (2005 to 2009), panelists forecast more restrictive standards in all of the areas under consideration.

As noted in "other responses" and comments, panelists also identify numerous other areas where more restrictive legislation is possible.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following tables.

LEGISLATION/REGULATORY ACTIVITY SHORT TERM PASSENGER CAR	MANUFACTURER MEAN	SUPPLIER MEAN
OCCUPANT RESTRAINT/INTERIOR SAFETY	2	2.3
VEHICLE EMISSION STANDARDS	1.8	2.1
VEHICLE INTEGRITY/CRASHWORTHINESS	2.1	2.4

Manufacturers anticipate more restrictive regulations than do suppliers in the areas of occupant restraint/interior safety, vehicle emission standards, and vehicle integrity/crashworthiness.

TREND FROM PREVIOUS DELPHI SURVEYS

Results for the current and previous three surveys are quite similar, with the exception of the current survey forecasting somewhat more restrictive legislation for vehicle emissions short and long term and regionalization of standards long term.

STRATEGIC CONSIDERATIONS

Panelists forecast increased regulation of the vehicle in many areas in the long and short term. As noted in the comments, politics will play a major part in determining the final outcome.

Legislators should consider the balance between cost of additional or more restrictive standards and the anticipated benefit to society. Technical feasibility of required changes should also be considered.

A proactive role in design and development on the part of vehicle manufacturers in many of the areas under consideration may result in regulations that more reasonably balance cost versus benefit.

Vehicle-emission standards for greenhouse gases (carbon dioxide) are likely to receive attention in the near future as global warming receives increasing attention. Regulations to reduce carbon dioxide emissions will have far-reaching impact on the automobile industry, because the only way to reduce such emissions is to increase vehicle fuel economy or use alternative fuels or energy sources. With the low price of gasoline, fuel economy improvements will not be consumer driven. Many customers prefer relatively large, functional vehicles, considering the relatively low cost of fuel.

TECH-13 How likely are federal or state government legislation and regulations to require changes in the recyclability of automotive materials in 2009?

SCALE →	1	3	5
	EXTREMELY LIKELY	SOMEWHAT LIKELY	NOT AT ALL LIKELY

REGULATORY ISSUES	2009 MEAN RESPONSE
BAN ON SOME CURRENT AUTOMOTIVE MATERIALS	2.6
ESTABLISHMENT OF UNIFORM IDENTIFICATION/CODING STANDARDS FOR MATERIALS TO FACILITATE SEPARATION	2.1
FINANCIAL PENALTIES/INCENTIVES BASED ON RECYCLED CONTENT	2.8
MINIMUM RECYCLED CONTENT	2.5
SPECIFIC REGULATION FOR THE FOLLOWING:	
DISPOSAL OF AUTOMOTIVE FLUIDS	1.9
DISPOSAL OF USED TIRES	1.9
RECYCLABILITY OF PLASTICS/POLYMERS	2.1
"TAKE BACK"' REGULATIONS MAKING MANUFACTURERS RESPONSIBLE FOR FINAL PRODUCT DISPOSITION	3.4

SELECTED EDITED COMMENTS

- Globalization of the automotive industry will mandate this for the cross pollination and export of vehicles.
- Little emphasis on recycling and information to the public by either public or private sectors. May have early trade-ins encouraged with incentives to get less efficient, greater-polluting vehicles off the road.

RESULTS SUMMARY

Panelists forecast that federal or state governments are somewhat likely to require recyclability in several areas related to automotive materials by 2009. Legislation and regulations are considered quite likely in the areas of establishment of uniform identification/coding standards for materials to facilitate separation, disposal of automotive fluids, disposal of used tires, and recyclability of plastics/polymers.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

Results of the current and past four surveys are in very close agreement. Legislation and regulation considered likely in early surveys have not materialized to date.

STRATEGIC CONSIDERATIONS

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 to use recycled plastic will be developed and will alter our views on the recyclability of automotive materials.

Most of the vehicle is recycled today and items not recycled today may prove challenging to recycle in the future. This is particularly true of plastic components. Manufacturers are actively working on recycling, and we can expect to see advances in this area. Clearly, this is one area where the industry is ahead of the North American regulatory process. One consequence of this is the likelihood that the industry has earned the right to participate in the future regulatory process.

TECH-14 How important are these elements of competition currently and in the year 2009?

SCALE →	1 VERY IMPORTANT	3 SOMEWHAT IMPORTANT	5 NOT IMPORTANT

KEY ELEMENTS	CURRENTLY	2009
	MEAN RESPONSE	MEAN RESPONSE
CORPORATE PRODUCT REPUTATION	1.7	1.7
COST TO THE MANUFACTURER	1.9	1.8*
ENVIRONMENTAL RESPONSIBILITY	2.8	2.1*
FIT AND FINISH	2.0	1.9
FUEL ECONOMY	3.3	2.2*
IMAGE AS A GOOD CORPORATE CITIZEN	3.0	2.6*
NEW TECHNOLOGY/PRODUCT INNOVATION	2.5	2.0*
PERFORMANCE	2.1	2.2
QUALITY/RELIABILITY/DURABILITY (QRD)	1.6	1.6
REDUCED LEAD TIME	2.6	2.2*
RIDE AND HANDLING	2.4	2.3*
SAFETY	2.1	1.7*
SALES AND SERVICE	2.2	1.9*
STYLING/FASHION	2.0	2.0
VEHICLE ERGONOMICS	2.6	2.3*
VEHICLE SALES PRICE	1.9	1.8*

*Indicates a significant different in current/2009 comparison.

SELECTED EDITED COMMENTS

- All of the above are important, but relative rankings/weight is the key issue. Everything is becoming more important because the market is becoming more competitive!!!
- Cars are rapidly becoming more than acceptable in most categories, such as fit/finish, performance, quality, and safety. Incremental improvements will not be discernable to all, except the most sophisticated driver, and will only serve to drive up cost; which is, has always been, and always will be, the most important element.
- Each company/product team will seek a unique "balance" to optimize these attributes for their situation.
- More emphasis on vehicle interiors as the consumer base becomes more and more educated.
- Service or maintenance will decrease as the vehicles will have longer service intervals.
- The fuel economy, of course, depends heavily on political/economic world situations.
- The issue is how to differentiate a commodity like transportation.

RESULTS SUMMARY

Most elements of competition are currently considered to be quite important to panelists. Those elements that are considered to be only somewhat important are environmental responsibility, fuel economy, image as a good corporate citizen, reduced lead time and vehicle ergonomics.

In the year 2009, all elements are forecast to be important, with the exception of "image as a good corporate citizen," which is forecast to be somewhat important.

MANUFACTURER/SUPPLIER COMPARISON

There is one statistically significant difference in responses among manufacturers and suppliers. Manufacturers rate the sale-and-service element higher than do suppliers, both currently and in 2009.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was asked for future importance for the first time in the 1998 Delphi IX. There was very good agreement among Delphi X and Delphi IX panelists for future importance of elements of competition.

Current importance of elements was first addressed in the 1994 Delphi VII forecast. There is very good agreement among the current and past survey panelists with the exception of the elements shown in the following table.

CURRENT ELEMENTS OF COMPETITION	MEAN RESPONSE			
	1994 DELPHI VII	1996 DELPHI VIII	1998 DELPHI IX	2000 DELPHI X
ENVIRONMENTAL RESPONSIBILITY	2.2	2.2	3.3	2.8
FUEL ECONOMY	2.2	2.6	3.0	3.3
IMAGE AS A GOOD CORPORATE CITIZEN	2.4	2.9	3.0	3.0
REDUCED LEAD TIME	2.2	1.8	2.1	2.6

There is a trend toward less importance placed on each of the elements of competition, which is different from previous forecasts.

STRATEGIC CONSIDERATIONS

Automobile manufacturers are faced with a myriad of conflicting goals and objectives. The manufacturer that best balances these elements will profit best in the marketplace. It is apparent from the responses to this question, however, that panelists rate all elements of competition at least somewhat important. Manufacturers are not at liberty to ignore any of these factors.

It is interesting to note that fuel economy has decreased in importance in each of the past three forecasts. Perhaps this should not be surprising considering that the forecasts for increased fuel prices have not come to pass. The decrease in importance of fuel economy can also be observed in the marketplace by the trend towards larger vehicles and the shift from passenger cars to light trucks, sport utilities, and vans.

Certainly not all customers have the same priorities in considering purchase of a vehicle. It is important that the elements of competition are considered against the market segment of

the vehicle. For example, vehicle sale price may be very significant in an entry-level vehicle, but of lesser importance in a luxury vehicle. Conversely, fit and finish may have higher priority in a luxury vehicle than in an entry-level vehicle. It is very important that the vehicle design team have clearly defined priorities for elements of competition prior to beginning the design of the vehicle.

Another important consideration is that a manufacturer may excel at most factors of competition and have a failing grade in but a few. Yet, if they pick the wrong "few," this could be devastating in the market which, indeed today, is a true "jungle."

II. ENGINEERING AND SOURCING ISSUES

TECH-15 What percentage of product design and engineering activity for North American-produced passenger cars is and will be performed in North America and offshore by Ford, GM, and DaimlerChrysler and by foreign-owned vehicle manufacturers? Please provide your estimate for current activity.

DESIGN/ENGINEERING SITE	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST.	2004	2009	CURRENT EST.	2004	2009
FORD, GM, AND DAIMLERCHRYSLER						
NORTH AMERICA	80	75	70	80/90	70/80	52.5/72.5
OFFSHORE	20	25	30	10/20	20/30	27.5/45
FOREIGN-OWNED						
NORTH AMERICA	15	25	30	10/20	17.5/30	20/40
OFFSHORE	85	75	70	80/90	70/85	60/80

SELECTED EDITED COMMENTS

- I don't foresee much shifting of development engineering and core engineering, although some may occur in the second- or third-tier suppliers for both Foreign-owned and the Big Three. The trend toward styling for individual markets may increase.
- Lead engineering technology is in Europe and Japan.
- Trend toward "modules" will accelerate, resulting in a more global distribution of design work.

RESULTS SUMMARY

Panelists forecast that 70 percent of product design and engineering will be performed in North America by Ford, GM, and DaimlerChrysler in 2009 compared with 80 percent currently. They also forecast that 30 percent of product design and engineering will be performed in North America by foreign-owned manufacturers in 2009 compared with 15 percent today.

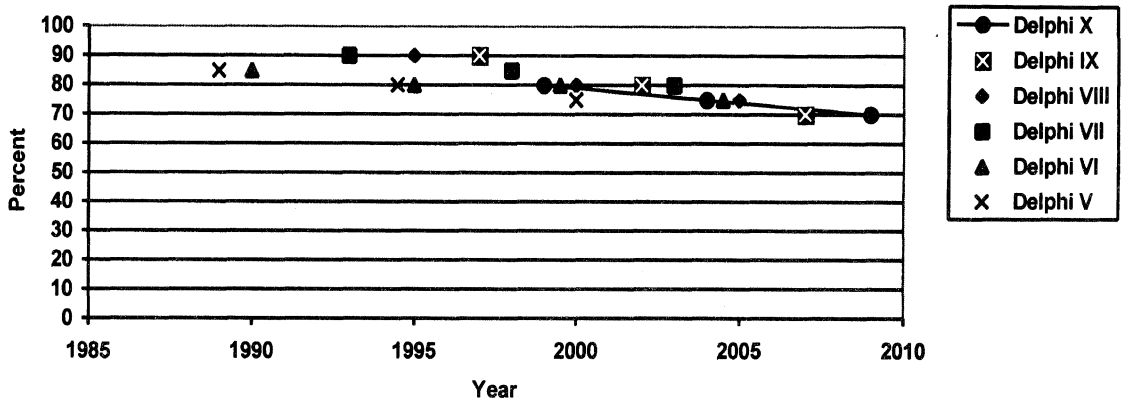
MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

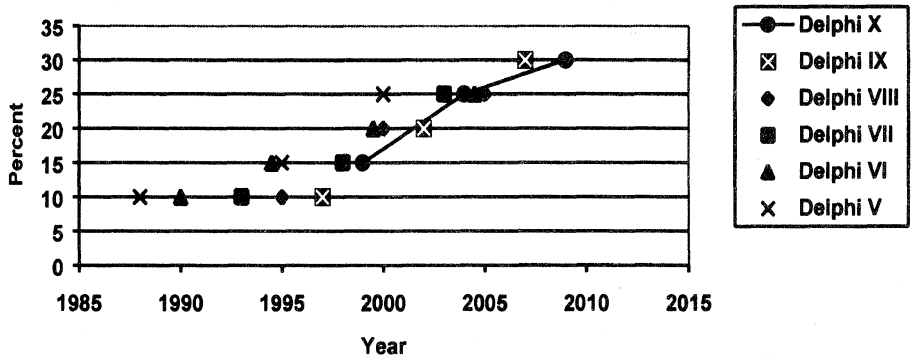
A comparison of results for this survey and the previous four surveys for design and engineering by Ford, GM, and DaimlerChrysler in North America is summarized in the graph below.

Product Design and Engineering in North America by Ford, GM, and DaimlerChrysler



Results of the current forecast are in close agreement with the previous three forecasts, Delphi VII through IX. Delphi V and VI forecast that the current percentage of North American design and engineering for Ford, GM, and DaimlerChrysler would be at or slightly below the current estimate of 80 percent.

Foreign-Owned Vehicle Manufacturers North American Product Design and Engineering Activity Forecast



The move by foreign-owned manufacturers to design and engineer products in North America has not progressed at a rate forecast in earlier Delphi forecasts; but it is clearly progressing to higher levels.

STRATEGIC CONSIDERATIONS

With the increasing globalization of the automobile industry, it had been forecast that Ford, GM, and DaimlerChrysler would conduct an increasing share of the design and engineering for North America outside of North America. While this has taken place to some extent, the rate of change has not been as great as previously forecast. This is also true of the shift to North America for design and engineering by foreign manufacturers. The rate of change has not met previous forecasts. In fact, many companies are advocating 24-hour engineering by literally using resources around the world virtually linked to increase the overall pace of engineering.

There are many ramifications to moving the locations of design and engineering. There is certainly advantage to engineering being located near suppliers. It is important that manufacturers and suppliers work closely early in the design of the product. This is easier when distance, culture, and language are not issues. There is also an advantage to having all engineering for a vehicle done in one location when traditional methods are used. This may be changing as new tools and information technology becomes available.

Engineering and styling/design work closely in the early design of the vehicle. This is considerably easier if the two are done in close geographic proximity, but this, too, may be changing.

Engineering also must work closely with manufacturing and assembly plants prior to production and in the early phases of production. This would be an incentive to locating engineering near to the assembly plant.

Systems engineering issues are simplified if all components of the vehicle are designed and sourced in near proximity to each other, but this, too, is not as clearly tied to geographic proximity as in the past.

High cost is a negative factor in designing in North America. This is an incentive for domestic manufacturers to design offshore, and a disincentive for foreign-owned manufacturers to move engineering to North America, although it depends on regional comparisons and competency available.

These factors, and others, may be considerations in the location of engineering and design. It may be that the learning curve in this area is simply not as steep as expected earlier, perhaps reflecting the complexity of the issue.

TECH-16 Manufacturers source parts, components, and subassemblies on a worldwide basis for their North American assembly plants. What percentage of parts, components, and subassemblies do these groups of vehicle manufacturers source from these regions currently, and what percentage will they source in 2004 and 2009? Please use a dollar-value basis in estimating percentages, and assume no changes in domestic-content legislation.

GLOBAL SOURCES FOR NORTH AMERICAN ASSEMBLERS	FOR NORTH AMERICAN ASSEMBLY					
	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST.	2004	2009	CURRENT EST.	2004	2009
BIG THREE (FORD, GM, DAIMLERCHRYSLER)						
JAPANESE SOURCES	10	10	10	8/16.3	7.8/15	5/15.3
NORTH AMERICAN SOURCES	70	69.5	60	60/80	50/75	50/70.3
WESTERN EUROPEAN SOURCES	10	11	10.5	7/16.3	8/20	6.8/20
ALL OTHERS SOURCES	5	10	10	5/10	5/15	5/25
ALL OTHER NORTH AMERICAN ASSEMBLERS (TOYOTA, HONDA, ETC.)						
JAPANESE SOURCES	50	43	40	35/60	30/50	25.8/45
NORTH AMERICA SOURCES	40	40	40	30/50	35/50	30/50
WESTERN EUROPEAN SOURCES	8	7	10	5/12	5/15	5/15
ALL OTHER SOURCES	5	10	10	5/10	5/15	5/19.3

SELECTED EDITED COMMENTS

- Currently, almost all new components, subassemblies, and modules are sourced on a global basis. As older designs are phased out, everything will become "global."
- Delphi and Visteon will become much tougher competitors after independence, slowing and possibly even eventually reversing gains made by Japanese suppliers. The European suppliers will always be handicapped by high costs due to the culture that they operate in.
- Sources located in India and China will exhibit substantial growth.

RESULTS SUMMARY

Panelists forecast a decrease in North American sourcing of parts, components, and subassemblies by the Big Three (Ford, GM, DaimlerChrysler) from 70 percent currently to 60 percent in 2009. Sourcing for all other North American assemblers (Honda, Toyota, etc.) from Japan is forecast to decrease from 50 percent currently to 40 percent in 2009. Sourcing from North America is forecast to remain unchanged.

MANUFACTURER/SUPPLIER COMPARISON

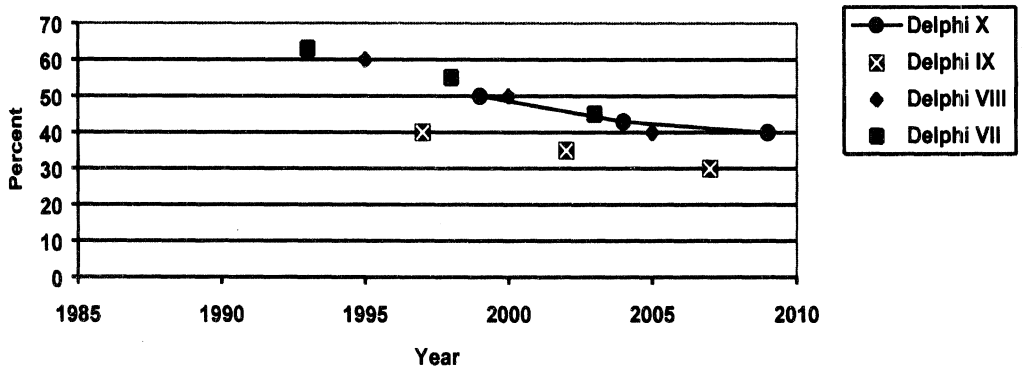
There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

TREND FROM PREVIOUS DELPHI SURVEYS

The percentage of parts, components, and subassemblies forecast to be sourced outside of North America (from Japan) by the all other North American assemblers (Honda, etc.) is summarized in the following graph for this and the previous five Delphi surveys.

The results of this forecast are in general agreement with previous forecasts, with the exception of the 1998 forecast, Delphi IX, with the current estimate on the high side of previous forecasts.

Sourcing for Other North American Assemblers from Japan



STRATEGIC CONSIDERATIONS

The forecast decrease in sourcing from North America by the Big Three may be a result of several factors. These include labor costs and suppliers following the location of vehicle assembly. A significant comment from a previous forecast is that many components supplied to traditional vehicle manufacturers will be manufactured in North America by foreign suppliers.

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 manufacturers abroad 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 likely increase.

Sourcing from Japan by assemblers other than the Big Three is forecast to decrease from 50 to 40 percent by 2009. This may put increased pressure on Japanese suppliers to sell more product to the Big Three. The already intense competition between global suppliers may become more intense in the future.

It should be noted that the decrease in sourcing from North America to the Big Three is all expected to take place in the time period between 2004 and 2009.

TECH-17 Please focus on the manufacturers' sourcing within North America for their North American assembly plants. What percentage of parts, components, and subassemblies do these groups of vehicle manufacturers source from these regions currently, and what percentage will they source in 2004 and 2009? Please use a dollar-value basis in estimating percentages, and assume no changes in domestic-content legislation.

SOURCES FOR NORTH AMERICAN ASSEMBLERS	FOR NORTH AMERICAN ASSEMBLY					
	MEDIAN REPONSE			INTERQUARITLE RANGE		
	CURRENT EST.	2004	2009	CURRENT EST.	2004	2009
BIG THREE (FORD, GM, DAIMLERCHRYSLER)						
CANADIAN SOURCES	15	15	15	10/20	10/20	10/20
MEXICAN SOURCES	15	20	25	10/20	15/30	20/35
UNITED STATES SOURCES	70	60	55	60/75	51.5/70	50/65
ALL OTHER NORTH AMERICAN ASSEMBLERS (TOYOTA, HONDA, ETC.)						
CANADIAN SOURCES	10	10	10	5/20	7/20	5/20
MEXICAN SOURCES	11	20	25	9.3/20	10/25	15/35
UNITED STATES SOURCES	75	65	60	60/85	55/78	50/70

SELECTED EDITED COMMENTS

- Delphi and Visteon will become much tougher competitors after independence, slowing and possibly even eventually reversing gains made by Japanese suppliers. The European suppliers will always be handicapped by high costs due to the culture that they operate in.
- Mexico's lower labor costs give it a competitive advantage.

RESULTS SUMMARY

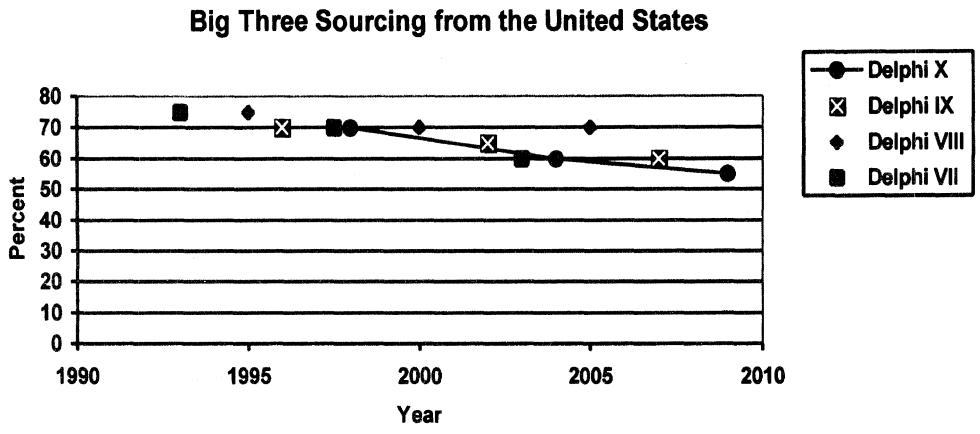
Panelists forecast that sourcing from the United States by the Big Three will decrease through 2009, as sourcing from Mexico increases. A similar trend is forecast for sourcing by all other North American assemblers. Sourcing from Canada is forecast to remain unchanged.

MANUFACTURER/SUPPLIER COMPARISON

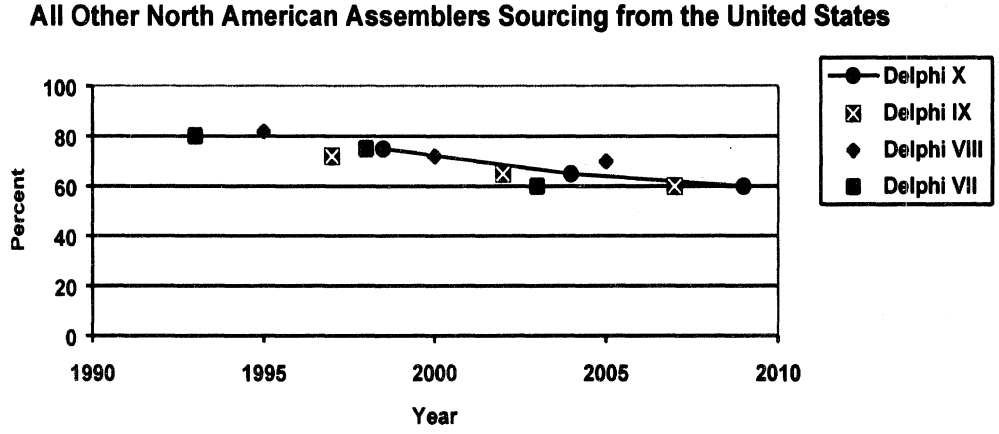
There are no statistically significant differences in responses between manufacturers and suppliers.

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. In previous forecasts, the Big Three included Chrysler, not DaimlerChrysler.



Results of the current survey are in general agreement with those of the previous three surveys.



Results of the current survey are similar to those of the previous three 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. Forecasts that Mexican workers would benefit from NAFTA at the expense of workers in the United States may be accurate, unless these lower labor rates help grow the market.

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 to 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-18 How much outsourcing of components and subsystems/modules will be done by first-tier suppliers and OEMs by 2004 and 2009? Please estimate what proportion of dollar value of components and subsystems will be carried out by first-tier suppliers and OEMs by 2004 and 2009. Please provide your estimate for current percentages.

	COMPONENTS					
	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST. (%)	2004 (%)	2009 (%)	CURRENT EST. (%)	2004 (%)	2009 (%)
1ST TIER SUPPLIERS	30	40	50	30/35	35/45	40/55
OEMs	50	52.5	55	50/55	50/60	50/64.5

	SUB-SYSTEMS/MODULES					
	MEDIAN RESPONS			INTERQUARTILE RANGE		
	CURRENT EST. (%)	2004 (%)	2009 (%)	CURRENT EST. (%)	2004 (%)	• 2009 (%)
1ST TIER SUPPLIERS	10	20	30	10/15	15/25	20/35
OEMs	40	45	50	30/50	40/50	45/55

SELECTED EDITED COMMENTS

- As e-commerce becomes widely used, OEMs will go more directly to suppliers, eliminating the middleman.
- I believe unions will stop most subsystem and module outsourcing at the OEMs.
- The OEMs are letting go slowly.
- Trend toward modularity will continue; however, it is very difficult to predict the rate pending resolution of labor issues and other considerations.
- Components will move to tier two.
- OEM engineers are still too cautious concerning outsourcing. This will slow the process. Whereas OEM engineers are still too cautious, tier one engineers are overconfident in their ability to design and integrate a module.
- OEMs will outsource as much as UAW contracts will allow. OEMs are turning into marketing and finance units. Manufacturing is just a burden.
- Shift to tier ones over time.
- Tier one (and tier two) will be doing more of the outsourcing as modularity grows.

RESULTS SUMMARY

Panelists forecast a modest increase in outsourcing by OEMs, but a marked increase in outsourcing by first-tier suppliers of components and subsystems/modules by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not included in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

The forecasts in this question are good news for tier-two and tier-three suppliers. Both OEMs and first tier suppliers are forecast to increase outsourcing of components and subsystems/modules through 2009. This is not good news, however, for OEM workers, and perhaps some first-tier workers as well. For first tier suppliers, it depends on how much they take over from OEMs, compared with how much they transfer to lower-tier suppliers.

As always, cost is the driving force behind such a move. As noted in the comments, however, there may be roadblocks put in the path of outsourcing by labor unions.

One of the panelist comments is noteworthy regarding the possible overconfidence of tier-one engineers related to their ability to design and integrate a module. Systems engineering is currently a major challenge. The farther the component or subsystem/module design is removed from the OEM, the greater will be the challenge of integrating it into the vehicle. This will take considerable effort on the part of OEMs as well as suppliers down the supply chain. The potential for quality and performance deficiencies are considerable if systems engineering is inadequate.

TECH-19 Please give your expectations in months for current and future development cycles from concept approval through Job One of high-volume passenger cars, maintaining current hardpoints and for establishing new hardpoints. High volume vehicles are those with production in excess of 50,000 units per year.

FUTURE DEVELOPMENT CYCLES	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT (MOS.)	2004 (MOS.)	2009 (MOS.)	CURRENT (MOS.)	2004 (MOS.)	2009 (MOS.)
MAINTAINING CURRENT HARDPOINTS						
EUROPEAN-BASED COMPANIES	36	30	28	30/40	25/36	20/36
GM, FORD, DAIMLERCHRYSLER	32	28	24	28/36	24/32	18/28
JAPANESE-BASED COMPANIES	25	23	19	22.5/31.5	18/28	16/24
ESTABLISHING NEW HARDPOINTS						
EUROPEAN-BASED COMPANIES	42	36	30	36/49	32/41.5	28/37
GM, FORD, DAIMLERCHRYSLER	38	32	28	36/42	30/36	24/32
JAPANESE-BASED COMPANIES	30	28	24	28/36	24/32.8	19/29

SELECTED EDITED COMMENTS

- "Fast" product capability may be constrained by economic-payback lifecycle considerations.
- Time to market is the issue.

RESULTS SUMMARY

Panelists forecast that total-development-cycle time for high-volume vehicles will be reduced by 22 to 25 percent for all manufacturers by 2009 maintaining current hardpoints and by 19 to 26 percent establishing new hardpoints.

Japanese manufacturers are forecast to retain their lead in cycle time over Ford, GM, and DaimlerChrysler and European-based manufacturers in this timeframe.

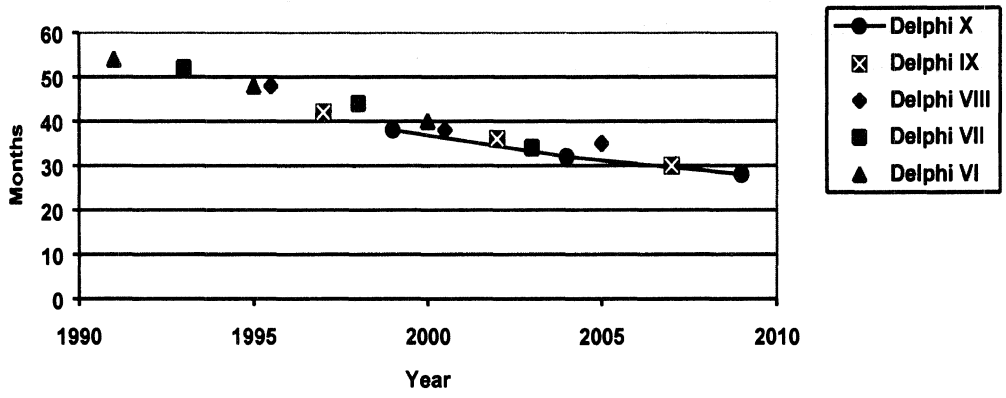
MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

There is good agreement between the current forecast and the previous four forecasts for current and new hardpoints for all manufacturers. An example of the trend is shown in the following graph.

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



STRATEGIC CONSIDERATIONS

Reducing development-cycle time allows a manufacturer to bring a product to market closer to the time that the requirements of the market are defined. The Japanese have shorter cycle time than Ford, GM, and DaimlerChrysler and European-based manufacturers. They therefore have a competitive advantage in this regard. Panelists forecast that this advantage will decrease by 2009, however.

When the clock starts on measuring cycle timing is certainly an issue. 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 the consensus that cycle time has been reduced by about 30 percent since 1992 and is forecast to be reduced another 26 percent by 2009.

Management that provides clear direction early in the design phase and does not change that direction during the design-and-development process will contribute greatly to reduced cycle time. The worst scenario for product quality is for management to dictate cycle timing, and to change product definition late in the design/development process. This results in components, systems, and processes that are inadequately validated. This scenario has been identified as a major cause of the past gap in quality between Japanese and domestic vehicles. To the credit of the domestic manufacturers, as the gap in cycle time has decreased between Japanese and domestic manufacturers, the gap in quality has also decreased dramatically.

Another key factor in reduced cycle time is an organization that has clearly defined authority as well as responsibility for the vehicle.

It is useful to consider the quartile ranges indicated. These ranges are a measure of the uncertainty of a given forecast and/or the fact that manufacturers have different strategies or competencies. The performance of the best organizations, therefore, are likely to become represented by either the upper or lower quartile point, depending on what is best. For example, consider the forecast for Big Three product development with existing hardpoints in 2009. The median forecast is 24 months, but the lower quartile is only 18 months, which suggests that the best performance is more likely to have an 18- rather than 24-month development time for a redesign with existing hardpoints.

TECH-20 Please rate the technology leadership of each regional industry today and in the future. Please consider both manufacturers and suppliers.

SCALE →	1	3	5
	TECHNOLOGY LEADER	NEITHER TECHNOLOGY LEADER NOR FOLLOWER	TECHNOLOGY FOLLOWER

REGIONAL INDUSTRY	TODAY	2009
	MEAN RESPONSE	MEAN RESPONSE
PRODUCT TECHNOLOGY		
EASTERN EUROPE	4.9	4.0*
JAPAN	1.8	1.8
KOREA	3.9	3.2*
NORTH AMERICA	1.9	1.7*
SOUTH AMERICA	4.5	4.0*
WESTERN EUROPE	1.8	1.6
PROCESS TECHNOLOGY		
EASTERN EUROPE	4.7	3.9*
JAPAN	1.4	1.5
KOREA	3.6	3.0*
NORTH AMERICA	2.0	1.7*
SOUTH AMERICA	4.4	3.7*
WESTERN EUROPE	2.4	1.9*

*Indicates significant different in current/2009 comparison.

SELECTED EDITED COMMENTS

- Because of the globalization of manufacturers and suppliers, technology leadership will be corporate, not regional.
- Processing will be the key.
- Processing will diffuse worldwide.

RESULTS SUMMARY

For current product technology, there are no statistically significant differences in panelists' responses for Japan, North America, and Western Europe. They are rated equal in product technology.

For current process technology, panelists rate Japan as the best, followed closely by North America and Western Europe.

By 2009, panelists forecast that product technology leadership will be in Western Europe, followed very closely by North America and Japan. In the same time frame, panelists forecast that Japan will be the leader in process technology, followed closely by North America and Western Europe, in that order.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers, with the exception of the items shown in the following tables.

REGIONAL INDUSTRY	MANUFACTURER MEAN	SUPPLIER MEAN
PRODUCT TECHNOLOGY		
EASTERN EUROPE TODAY	4.9	4.5
PROCESS TECHNOLOGY		
EASTERN EUROPE 2009	4.2	3.8

TREND FROM PREVIOUS DELPHI SURVEYS

There is very good agreement between the current and past three Delphi forecasts, with the following exceptions.

Current panelists rate both product and process technology in Western Europe 0.5 rating points higher than past panelists for both the current and 10-year-later periods.

In general, the performance gaps between Japan, North America, and West European manufacturers are perceived to be closing more than suggested in previous forecasts.

STRATEGIC CONSIDERATIONS

It should be noted that these forecasts are for the aggregate industry in each area. Significant variations can occur between companies within a given region.

Leadership in product and process technology will allow a manufacturer or supplier to compete effectively in our increasingly global market. Prudent use of this technology will result in reduced cost and development time, as well as increased quality and customer satisfaction. Vehicles can also be enhanced by technology through the application of leading-edge features, as well as advancements in system capability. There is no area of the vehicle that cannot be improved through the application of technology. This will be true to an even greater extent in the future as the vehicle becomes more complex as a result of more features or greater sophistication in existing features.

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 industry 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.

Of course, a company can have terrific technology and execute effectively, but unless it is directed appropriately at the intended customer base, it will not be effective.

Regions with perceived low technical capability, such as Korea, may have offsetting advantages such as low cost.

TECH-21 What percentage of vehicle engineering is done using math and computer-based tools (CAE) currently and will be in 2004 and 2009? [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.]

PERCENTAGE OF VEHICLE ENGINEERING UTILIZING COMPUTER-BASED TOOLS						
1997* (%)	CURRENT 1999 (%) MEDIAN	2004 (%) MEDIAN	2009 (%) MEDIAN	CURRENT 1999 (%) INTERQUARTILE RANGE	2004 (%) INTERQUARTILE RANGE	2009 (%) INTERQUARTILE RANGE
30	40	50	70	35/41.3	43.8/60	60/81

*Delphi IX, OSAT estimate.

SELECTED EDITED COMMENTS

- If the technological advancements in computer-based technology continue at the present pace, the percentage will be even higher.
- Moore's Law of increasing CPU capability (doubling of CPU power every two years) is the key enabler here. If it continues to hold, simulation capability will continue to expand to the limit of available capability.
- Programs (computer) are getting easier to use, resulting in more widespread use.
- Virtually all aspects of engineering analysis will be computerized, to speed up development, and to facilitate hiring engineers without the skills to perform the analysis manually.

RESULTS SUMMARY

Panelists forecast that 70 percent of vehicle engineering will be done using math- and computer-based tools (CAE) by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was asked for the first time in the 1998 Delphi IX forecast. The results of that survey and the current survey are the same.

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
- reduced manufacturing costs

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. This trend is noted in the comment of one of our panelists. Manufacturers and suppliers will be challenged to keep abreast of the latest developments in this area and to ensure 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.

One interesting point that is just now becoming apparent is that the prototypes we have historically relied on as a development tool may not be as effective as once thought. Increasingly, we are seeing the match model as a better representation of the geometry than a physical prototype. The explosive increase in use of CAE tools represents a revolution in the vehicle-engineering process.

TECH-22 There is a growing interest in math-based engineering, or computer-aided engineering (CAE), to reduce prototype and testing requirements. What impact do you expect from this technology on the cost and timing of product development by the years 2004 and 2009? Please express as percentage reduction in cost and timing from current process. (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.)

IMPACT OF MATH-BASED ENGINEERING (OR CAE)	PERCENTAGE REDUCTION			
	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004	2009	2004	2009
COST	10	20	5/20	11/32.5
TIMING	18	30	10/20	15/40

SELECTED EDITED COMMENTS

- 2004: Reduction in time and cost of first generation prototypes.
- 2009: Further reductions during the design optimization phase of the development cycle.
- As databases improve, model capabilities will increase so as to reduce testing.
- I think we are on the verge of significant levels of CAE systems integration that will lead to considerable short-term gain, but the rate of advance will probably slow by 2009.
- Large improvements are expected in some areas (i.e., crash simulation, structural analysis) but less progress in other areas (e.g., styling) will constrain the "total" benefit.
- Simulation and CAE is the answer but we must validate the simulations with real world experience.
- The real impact is higher-quality analysis.
- This is already showing benefits in reduced number of iterations of prototypes, very useful for the concept-validation process.

RESULTS SUMMARY

Panelists forecast that math-based engineering, or computer-aided engineering (CAE), will produce a reduction in vehicle-development cost of 20 percent and a reduction in timing of 30 percent by 2009.

MANUFACTURER/SUPPLIER COMPARISON

The statistically significant differences in response between manufacturers and suppliers are shown in the following table.

IMPACT OF MATH-BASED ENGINEERING (OR CAE)	PERCENTAGE REDUCTION	
	MANUFACTURER MEAN	SUPPLIER MEAN
TIMING – 2004	13.9	21.1

Suppliers forecast a greater reduction in timing than do manufacturers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was asked in the 1998 automotive Product Design and Development Delphi. The results of the two Delphi forecasts are in good agreement.

STRATEGIC CONSIDERATIONS

The strategic implications of timing were addressed in TECH-19.

The implications of reduction in cost are directionally obvious. The absolute value of the reduction in vehicle development cost may not be as obvious. It has been estimated that the cost of engineering a vehicle is somewhat less than 5 percent of the cost of a vehicle. This varies significantly between vehicles, and is highly dependent on the production volume of vehicles produced. The more vehicles that are produced, the less the cost per vehicle, assuming a constant development cost. Using the figure of 5 percent, the forecast cost reduction of 30 percent by 2009 would produce a reduction in vehicle cost of 1.5 percent. This is in the range of $300 per vehicle, which is a significant portion of the profit on a vehicle.

It is apparent that the efficient and widespread use of math-based engineering has the potential to significantly impact the profitability of a vehicle manufacturer.

It has been noted that a reduction in vehicle-development-cycle timing may also produce a reduction in cost. Therefore, the synergistic effect of cost and timing may result in a greater cost reduction than indicated by panelists' responses to this question.

As a word of caution, however, the comment of one of the panelists that math-based simulations must be validated with real-word experience should be noted.

Please see TECH-23 for a cautionary note regarding the results of this question with regards to cycle timing.

It is also important to note the quartile ranges in questions like this. It is possible that those whose forecast was closer to the upper or lower quartile numbers were actually more knowledgeable than the median respondents. In responses to questions like this, it might support that the most accurate result was either better or worse than the mean. Obviously, the rate of increase in use of CAE tools is very high, suggesting significant volatility in product-development performance. Clearly this is an important area to monitor closely.

Also, there are a number of different CAE areas, e.g., dynamic systems or structural analysis modeling. Not all areas are on the same learning curve. Hence, respondents more familiar with one area than another are likely to respond based on their area of knowledge.

TECH-23 What percentage of the overall reduction in product development time in your company will be due to each of the following sources? Suppliers, please answer for the OEM that is your largest customer.

SOURCE	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004 (%)	2009 (%)	2004 (%)	2009 (%)
MANAGEMENT DIRECTION	10	5	5/20	5/10
ORGANIZATION	10	10	5/15	5/10
PROCESS	11	15	5/20	8/20
STANDARDIZATION	10	15	5/20	5/20
SUPPLIER CAPABILITY	10.5	20	10/20	10/30
USE OF MATH AND COMPUTER TOOLS	20	25	10/25	15/30

SELECTED EDITED COMMENTS

- Improved systems engineering could also reduce development time.
- Management direction in the last five years has added time to development with QS9000, the fashionability of supplier growth, and a general lack of technical and business knowledge.
- My company now has a well-defined "process," but management discipline to follow it is clearly lacking. Large future gains will come from lessons currently being learned here and from a better planning process.

RESULTS SUMMARY

Panelists forecast that 25 percent of the overall reduction in product development time will be due to the use of math and computer tools, 20 percent due to supplier capability and 15 percent due to standardization by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

As noted in TECH-19 and TECH-22, development-cycle timing is forecast to decrease significantly by 2009. There is an inconsistency, however, between this and those previous two questions. In TECH-19, cycle time is forecast to decrease by 10 months, or about 26 percent by 2009. In TECH-22, cycle time is forecast to decrease approximately 30 percent by 2009 as a result of math-based engineering. This would indicate that the total reduction in cycle time would be due to math-based engineering. This does not agree with the results of this question. The responses to TECH-19 and 23 are probably accurate, and the reduction

due to math-based engineering is likely overstated in TECH-22. This could be due to the exclusive focus of the earlier questions.

In any event, it is a consensus that the greatest reduction in cycle timing will come as a result of math-based engineering, and that the magnitude of this reduction will be substantial. It is also clear that a number of factors are likely to be involved in the reduction of product-development time. There is not one silver bullet. This is a highly complex issue, requiring high levels of effort in many areas. Considerable coordination of many areas will be required to achieve the forecast results.

TECH-24 With the advent of improved simulation and analytical tools, the number of physical prototypes may be reduced in the years ahead. Using 1998 as a baseline, what percentage reduction in physical prototypes do you expect by 2004 and 2009?

PHYSICAL PROTOTYPES	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004 (%)	2009 (%)	2004 (%)	2009 (%)
FULL VEHICLE	20	40	10/26.3	20/50
CHASSIS/SUSPENSION	20	40	10/30	20/50
POWERTRAIN	20	30	10/25	15/50
SEAT	20	30	10/30	20/50

OTHER RESPONSES

- Electronic systems. 2004: 10%; 2009: 30%
- HVAC. 2004: 80%; 2009: 80%
- Interiors. 2004: 40%; 2009: 60%
- Interior bucks. 2004: 10%; 2009: 50%
- Safety systems. 2004: 5%; 2009: 5%
- Thermal and exhaust systems

SELECTED EDITED COMMENTS

- Efficiency improvements will be offset by increasing requirements driven by regulatory activity.

RESULTS SUMMARY

Panelists forecast reductions of 30 to 40 percent for the number of full vehicle and system prototypes by 2009 as a result of improved simulation and analytical tools.

MANUFACTURER/SUPPLIER COMPARISON

The statistically significant differences in responses between manufacturers and suppliers are shown in the following table.

PHYSICAL PROTOTYPES	MANUFACTURER MEAN	SUPPLIER MEAN
FULL VEHICLE 2004	24.8	15.5
FULL VEHICLE 2009	43.2	33.3
CHASSIS/SUSPENSION 2004	27	17.3
CHASSIS/SUSPENSION 2009	44.5	32.1

Manufacturers forecast a greater reduction in the number of full-vehicle and chassis/ suspension prototypes in 2004 and 2009 than do suppliers. Since these prototypes are generally built by manufacturers, it is likely that the manufacturers' estimate is more accurate.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was first asked in the 1998 forecast Delphi IX. There is very good agreement between the two forecasts.

STRATEGIC CONSIDERATIONS

The building and testing of prototype vehicles and systems consumes a large portion of total development cost. This forecast for the reduction of required prototypes represents a sizable reduction in total development cost.

Not all manufacturers or suppliers have equal capabilities in the area of simulation and analytical tools. Those that excel in this area will see increased profits or business opportunities as a result.

The comment regarding additional government regulation and requirements increasing the requirements for prototypes should be noted. This may slow the decrease in prototype requirements.

An issue of great significance regarding prototypes is that the math models in some cases may be a better, more accurate representation of a design than the physical prototype. In one study, we are familiar with regarding the use of math-based tools. The savings in manufacturing were more than an order of magnitude greater than the savings in engineering costs. This is due, presumably, to better, more manufacturable designs given to the production centers.

TECH-25 Please rate the following aspects of your organization's systems engineering.

	HOW FULLY IMPLEMENTED?		
SCALE →	1	3	5
	NEARLY 100%	ABOUT 50%	JUST STARTING

ASPECTS OF SYSTEMS ENGINEERING	MEAN RESPONSE
MANAGEMENT'S USE/EMBRACE OF SYSTEMS ENGINEERING	3.1
MIDDLE/SENIOR MANAGEMENT'S UNDERSTANDING OF SYSTEMS ENGINEERING	3.3
ITS EFFECTIVENESS IN YOUR ORGANIZATION	3.3

SELECTED EDITED COMMENTS

- Management embraces the words and concepts; however, they do not understand how to organize for "systems engineering," nor do they really understand what it means.
- The concepts and practices were never organizationally adopted/recognized to potential/execution. As time goes on, it seems that less and less is heard about systems engineering as an integral/key part of our vehicle-development process.
- The systems engineering approach is "baked" into our process and middle management understands it well. Top management does not understand it and sometimes sets a terrible example by directing actions totally inconsistent with our stated process. Eventually these folks will fade away and, hopefully, be replaced by those who better understand systems engineering.

RESULTS SUMMARY

Panelists rate systems engineering within their organizations as approximately 50 percent implemented.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi forecast in the same form.

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. Finally, a rigorous set of requirements for design, development, and manufacturing processes are defined for each step of the process, and adherence to these requirements is closely monitored throughout the design/development/manufacturing process.

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, upper management in some companies may not understand systems engineering, and may take actions that are contrary to the process. By so doing, quality, cost and customer satisfaction may be compromised.

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.

TECH-26a Manufacturers are seeking opportunities to source components in modules or systems. (a.) Considering likely modules in your area of the vehicle, please estimate the total cost reduction such an approach can achieve by 2004 and 2009.

	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004 (%)	2009 (%)	2004 (%)	2009 (%)
TOTAL AMOUNT OF COST REDUCTION	10	18	5/10	10/25

b. Please estimate how much of the reduction is due to the following sources.

SOURCE OF REDUCTION	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004 (%)	2009 (%)	2004 (%)	2009 (%)
ELIMINATION OF ENGINEERING DUPLICATION	10	10	5/20	5/20
ELIMINATION OF LABOR FROM THE ASSEMBLY PROCESS	20	20	10/25	10/28.8
REENGINEERED FOR MODULE OPTIMIZATION, NOT COMPONENT OPTIMIZATION	17.5	20	6.3/30	10/33
TRANSFER OF ENGINEERING FROM OE'S TO SUPPLIER	15	15	10/20	5/23.5
TRANSFER OF LABOR FROM OE TO SUPPLIER	20	20	10/40	10/30

OTHER RESPONSES

- Add new investments. 2004: 33%; 2009: 12%
- Add shipping logistics. 2004: 33%; 2009: 12%
- Bureaucracy reduction. 2004: 10%; 2009: 10%
- Common components. 2004: 15%; 2009: 5%
- Logistics. 2004: 10%; 2009: 20%
- Negotiations. 2004: 35%; 2009: 10%
- Product reengineering. 2004: 30%; 2009: 20%
- Sales, inventory, shipping etc. 2004: 20%; 2009: 20%
- Shorter engineering cycle time. 2004: 10%; 2009: 25%
- Squeezing of supplier profit margins. 2004: 20%; 2009: 15%

SELECTED EDITED COMMENTS

PART A:

- The key word is "can." I'm not sure how aggressive we will actually be given labor contracts.
- The reduction is based on no increase in performance or added functionality. A side benefit of the module can be added functionality and performance.
- Cost savings will vary widely between modules (interior vs. engine vs. suspension).

- What it can achieve and what it will achieve are very different. Labor will be the number one constraint here.

Part B:

- The biggest benefit is in bypassing labor contracts at the domestic automakers plants with $3/hour labor at suppliers' NAFTA plants.
- Reduction in OE supplier administration costs.
- The major savings will be at the OEM level. OEMs will hold a supplier to a higher standard than they hold themselves.
- The trend is for a less vertically integrated organization with suppliers doing more and more in the their field of expertise. Productivity, speed, quality, technology, and efficiency will be the benefits emerging from this restructuring.

RESULTS SUMMARY

Panelists forecast that a cost reduction of 18 percent can be achieved by 2009 by sourcing components in modules or systems.

The sources of this cost reduction are forecast to be a result of elimination of engineering duplication, elimination of labor from the assembly process, reengineering for module optimization, transfer of engineering from OEs to suppliers, and transfer of labor from OE to supplier.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers, as shown in the following table.

SOURCE OF REDUCTION	MANUFACTURER MEAN	SUPPLIER MEAN
ELIMINATION OF ENGINEERING DUPLICATION 2009	10.5	16.3
ELIMINATION OF LABOR FROM THE ASSEMBLY PROCESS 2009	23.3	16.3
TRANSFER OF LABOR FROM OE TO SUPPLIER 2004	32.9	20.3
TRANSFER OF LABOR FROM OE TO SUPPLIER 2009	27.9	18.4

Manufacturers forecast greater savings from elimination of labor from the assembly process and transfer of labor from OE to supplier than forecast by suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

Two panelists pointed out the use of the word "can," and noted that the achievement of the forecast results are highly dependent on labor contracts. In fact, we have already seen labor resistance to the introduction of modules on a large-scale basis into the assembly plant. The success of negotiations with labor will ultimately determine the achievement of the potential cost savings associated with the sourcing of components in modules or systems.

In order to remain cost competitive with foreign manufacturers, it is very important that the potential cost benefits from this approach to assembly be realized.

The entire issue of models is volatile, emotionally charged, and changing rapidly. Modules are not new. We have been using them routinely for many years, but in most cases, they were optimized at the part level rather than the system level. We could call these level-one modules. Significant progress is apparently being made in the development of what might be termed level-two modules, which are optimized at the system level. One key aspect of attaining level-two optimization is the relaxation of detailed requirements from the manufacturer that could "lock up" the designs and reduce the creativity of suppliers. A codesign process would seem desirable. This includes the manufacturers developing effective, functional specifications rather than detailed specifications and working jointly with tier-one and even tier-two suppliers. Progress in the development of modules must be monitored closely.

III. MATERIALS

TECH-27 What percentage change in total vehicle weight do you anticipate by 2004 and 2009? Please reference all percentage changes to current vehicles, indicate whether plus or minus.

VEHICLE TYPE	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004 (%)	2009 (%)	2004 (%)	2009 (%)
PASSENGER CAR	-1	-5	-5/5	-10/10
LIGHT TRUCK	0	0	-5/5	-11/10

SELECTED EDITED COMMENTS

- Increasing crash requirements will have an offsetting effect on fuel economy, driven by weight savings.
- It depends on CAFE and the federal government.
- The above numbers are contingent upon and dynamic to legal and competitive pressures.
- The limitations of cost and marketing drive vehicle weights up, so even ambitious vehicle-mass reduction programs tend to be neutralized.
- The market pull for more features, performance, and safety will offset increasing powertrain/vehicle efficiency. I do not expect this to change unless there is a major shift in fuel prices/availability, or unless CAFE legislation drives a change in customer or manufacturer behavior.
- There will be a general downsizing of the fleet due to government regulation and consumer awareness of environmental issues. The downsizing will be much greater in the light-truck segment.
- Trucks will continue to look more massive and will gain weight until something significant (taxes, gas prices, etc.) causes a design for lighter weight.

RESULTS SUMMARY

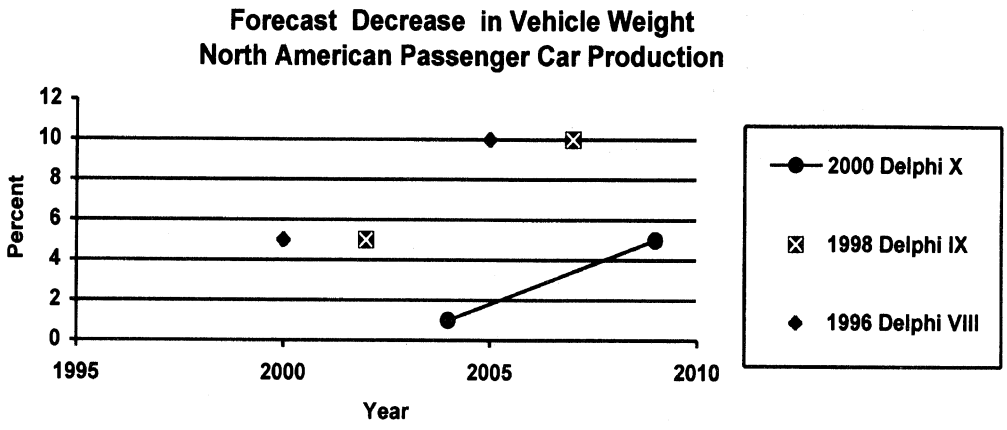
Panelists forecast a 5 percent decrease in passenger-car weight by 2009, and no change in light-truck weight in the same timeframe.

MANUFACTURER/SUPPLIER COMPARISON

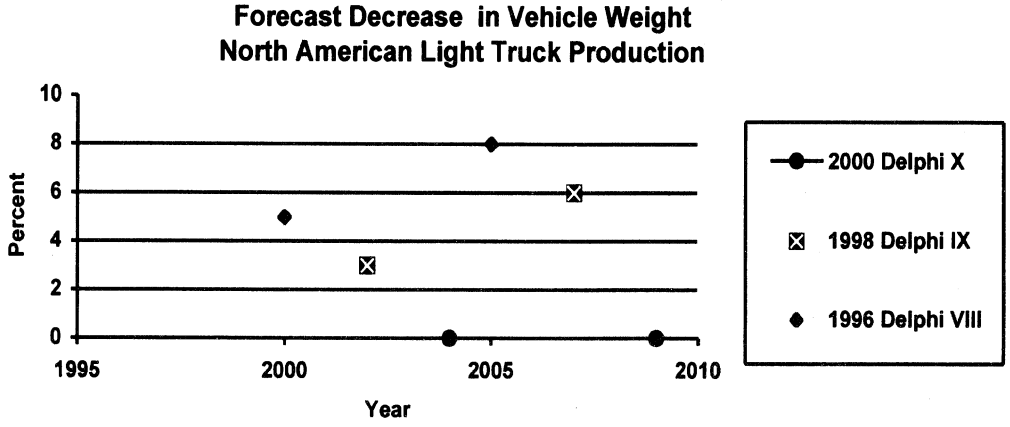
There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was first asked in the current format in the 1996 Delphi VIII forecast. A comparison of results of the current forecast and the previous two forecasts is shown in the following graphs.



For passenger cars, the previous two surveys forecast a weight reduction of 5 percent 5 years out and 10 percent 10 years out. This is a markedly greater reduction than forecast in the current survey.



For light trucks, the previous two surveys forecast a weight reduction of 3 to 5 percent 5 years out and 6 to 8 percent 10 years out. This is compared with a current forecast of no change.

STRATEGIC CONSIDERATIONS

Past weight-reduction forecasts have not come to pass. Average passenger car weight has actually increased almost 100 pounds since 1990 as a result of customer preference for larger vehicles with added optional functions. If you take into account the shift from passenger cars to light trucks, vans and SUVs, the average vehicle weight has increased measurably. This deviation from past forecasts is likely a result of the fact that past forecasts for increased fuel prices and CAFE standards have not been fulfilled. Actual fuel prices and CAFE standards compared with forecast prices and standards can be compared in TECH-1 and TECH-2, respectively.

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.

Until fuel prices or fuel-economy standards increase, it is unlikely that there will be any substantial decrease in vehicle weight, unless weight reduction can be achieved at little or no

cost. This may be possible with much better modeling techniques and improved systems-level design capabilities.

Finally, weight reduction may not be the most cost-effective method to improve vehicle fuel economy. Alternatives such as powertrain improvements must be considered.

TECH-28 Please forecast the materials content change in percentage for the average North American-produced passenger car for 2004 and 2009, given the indicated CAFE scenarios. Leave blank any materials with which you are unfamiliar. Please reference all percentage changes to base year (1998), and indicate whether plus or minus.

MATERIALS	1998*	MEDIAN RESPONSE			INTERQUARTILE RANGE		
		2004 27.5 MPG (%)	2009 30 MPG (%)	2009 35 MPG (%)	2004 27.5 MPG (%)	2009 30 MPG (%)	2009 35 MPG (%)
ALUMINUM	219 lbs.	9	14	17.5	5/10	10/20	10/30
CAST IRON	359	-5	-10	-20	-11/-5	-20/-10	-30/-10
CERAMICS	n/a**	1	2	4.5	0/5	0/6.5	0.3/9.3
COPPER	46	-0.5	-5	-6	-5/0.5	-10/0	-14.5/0
GLASS	95	0	0	-1	-2/0	-5/1	-7.5/1
MAGNESIUM	6.5	7.5	10	20	5/20	7.5/45	10/78.8
PLASTIC/COMPOSITE	243.5	10	15	20	5/15	9.3/20	11.5/30
POWDERED METAL	32.5	5	5	7	.5/10	1/15	1/15
RUBBER (INCLUDING TIRES)	139.5	0	0	-1	-2/0.5	-5/0.3	-10/0
STEEL	1810	-5	-10	-15	-10/-2	-20/-6	-23.8/9.3
ZINC DIE CASTINGS	13.5	2	3	4	0/5	0/10	0/10

*Source: Ward's Automotive Yearbook 1998.
**Baseline information not available.

SELECTED EDITED COMMENTS

- CAFE improvements using weight reduction is risky because it depends on commodity prices that OEMs can't fully dictate. Driving the market price down for tires or engine parts is easier in such a captive market, but the OEMs cannot fully dial in the price of plastics, magnesium, or even aluminum in the long term.
- The weight of glass in vehicles will decrease, but the total area of glass will increase. This will be accomplished by changing to thinner glass, replacing tempered glass with laminated, and the limited substitution of polycarbonate for glass.

RESULTS SUMMARY

Panelists forecast a 10 percent reduction in cast iron and steel by 2009 if CAFE standards are set at 30 mpg and 20 percent and 15 percent, respectively, if CAFE standards are set at 35 mpg. Conversely, lighter weight materials such as aluminum, magnesium and plastic are forecast to increase in use by 10 to 15 percent for CAFE standards of 30 mpg and 17 to 20 percent if CAFE standards are set at 35 mpg.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

MATERIALS	MANUFACTURER MEAN	SUPPLIER MEAN
COPPER 2004 27.5 MPG	0.4	-4.2
COPPER 2009 30 MPG	-1.2	-10.1
COPPER 2009 35 MPG	-2.3	-15.8

Suppliers forecast a greater decrease in the use of copper for all three scenarios than do manufacturers.

TREND FROM PREVIOUS DELPHI SURVEYS

There is generally good agreement with past surveys for forecasts with increased CAFE standards. The significant point is that increased CAFE forecasts have not been realized.

The following table shows actual material usage in 1990 compared with 1998, and the forecast usage for 1998 from the 1994 forecast Delphi VII for a constant CAFE of 27.5 mpg.

MATERIAL	*ACT. 1990	FORECAST 1998	*ACT. 1998
ALUMINUM	158.5	175	219 lbs.
CAST IRON	454	420	359
COPPER	48.5	48	46
GLASS	86.5	86.5	95
MAGNESIUM	4.5	5	6.5
PLASTIC/COMPOSITE	229	250	243.5
POWDERED METAL	24	25	32.5
RUBBER (INCLUDING TIRES)	136.5	135	139.5
STEEL	1716.5	1650	1810
ZINC**	18.5	18	13.5
TOTAL VEHICLE	2876	2812	2964

**Zinc: 1990 & 1998 forecast are all zinc. 1998 act. is only diecast.

*Source: Ward's Automotive Yearbook 1998.

Steel: A decrease in use of steel was forecast. The amount of steel used actually increased. The increase is likely a result of an increase in average vehicle size.

Aluminum: Aluminum use increased at a rate greater than forecast. This is likely an increase in the use of aluminum in engine cylinder heads, blocks, and some structural parts.

Cast Iron: Cast iron use decreased more than forecast. This is likely a result of the conversion of engine cylinder blocks and heads to aluminum.

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-2 is between the level assumed in the two scenarios for 2009 in this question. Higher CAFE standards will accelerate the move to lightweight materials.

The use of aluminum in body panels has long been forecast to increase, but usage remains limited to date because of high cost and manufacturing considerations.

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. 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, but if it is required to meet functional requirements and cost targets, recycling problems can be resolved.

Increasingly more effective systems analysis will undoubtedly have an increasing impact on material selection.

TECH-29 Please 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%.

AUTOMOTIVE COMPONENTS: EXTERIOR SURFACE PANELS	2004					
	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	STEEL (%)	PLASTIC (%)	ALUMINUM (%)	STEEL (%)	PLASTIC (%)	ALUMINUM (%)
DOORS	90	7	5	80/94	4.5/15	2/7.5
FRONT FENDERS	86.5	9	5	75/92.5	5/24.3	1/10
HOOD	80	7.5	10	65/90	2/17.3	5/20
REAR DECK	80	5	8	70/90	2/15	3/20
REAR QUARTER PANELS	90	5	5	75/95	2/20	1/10
ROOF	90	5	5	80/98	1/10	1/10

AUTOMOTIVE COMPONENTS: EXTERIOR SURFACE PANELS	2009					
	MEDIAN RESPONSE			INERQUARTILE RANGE		
	STEEL (%)	PLASTIC (%)	ALUMINUM (%)	STEEL (%)	PLASTIC (%)	ALUMINUM (%)
DOORS	80	11	10	60/90	6.5/30	5/20
FRONT FENDERS	70	15	10	50/85	10/35	5/15
HOOD	60	15	19	50/80	5/30	10/30
REAR DECK	65	10	15	50/80	5/30	8.8/25
REAR QUARTER PANELS	80	10	10	60/90	5/30	4.3/17.3
ROOF	80	10	10	60/94	2/20	4/20

SELECTED EDITED COMMENTS

- "Front fenders" should be broken down into upper and lower fenders.
- Weight savings will occur because the cost for material substitutions will drop. This drop will be driven by 1) process improvement, 2) cost to recycle improvement, and 3) re-usability.
- Steel will continue to be the dominant exterior panel material for high-volume vehicles but aluminum and plastic usage will slowly creep upwards.

RESULTS SUMMARY

Panelists forecast that steel will remain the dominant material for body panels in the next decade. A modest increase in the use of plastic and aluminum is forecast, however. The greatest use of aluminum in 2009 is forecast for hoods (19 %) and rear decks (15 %). The greatest use of plastic is forecast for front fenders (15%) and hoods (15%).

MANUFACTURER/SUPPLIER COMPARISON

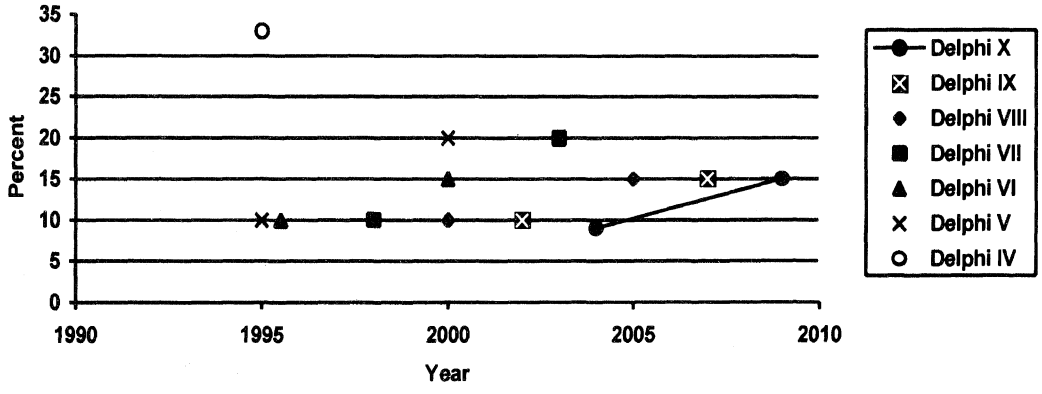
There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

The forecast for plastic body panels in the current survey is in general agreement with past surveys, with some exceptions. The 1987 forecast, Delphi IV, forecast 15 to 40 percent plastic body panels by 1995. Delphi V through Delphi IX generally forecast 5 to 10 percent use five years out, and 10 to 15 percent 10 years out. This is in agreement with the current survey, but forecasts of earlier surveys have not been realized.

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

Plastic Front Fender Forecasts



The trend for aluminum from past surveys is similar to that of plastics.

STRATEGIC CONSIDERATIONS

The forecast for increased use of plastic and aluminum in body panels from earlier Delphi forecasts has not been realized. This is likely a result of the fact that CAFE standards and gasoline prices have not increased as forecast. Manufacturers are very reluctant to add cost to a vehicle if it is not absolutely necessary. In at least one vehicle, plastic body panels have been replaced with steel in order to reduce cost.

The advancement in steel body thickness is also an important factor in the continued use of steel. Manufacturing considerations, as well as the reduced resistance to denting of aluminum, may also be factors. The increased dent resistance of plastics has not been a sufficient factor to displace less costly steel, except in the production of Saturns, where the voice of the customer said plastic in side panels.

Finally, recyclability and thermal-exchanger expansion problems also may be factors in the limited use of plastic body panels.

Still, the modest forecast for both aluminum and plastic body panels suggests intense competition is likely. All manufacturers are working very hard on body applications for light materials. New technology could, as it is developed, have a powerful impact on future body-material selection.

TECH-30 Assuming CAFE requirements at 27.5 mpg in 2004 and 30 or 35 mpg in 2009, what is the value today, in current dollars, per pound of weight saved to a vehicle manufacturer? What will it be in 2004 and 2009? Please use constant 1999 dollars without adjusting for inflation. Assume that the weight savings for the component or assembly under consideration does not change the test-weight class of the vehicle.

VALUE							
MEDIAN RESPONSE				INTERQUARTILE RANGE			
1999 CURRENT CAFE=27.5 MPG	2004 CAFE=27.5 MPG	2009 CAFE=30 MPG	2009 CAFE=35 MPG	1999 CURRENT CAFE=27.5 MPG	2004 CAFE=27.5 MPG	2009 CAFE=30 MPG	2009 CAFE=35 MPG
$1.00	$1.50	$2.00	$3.00	$1.00/2.00	$1.00/2.00	$1.50/3.00	$2.00/5.00

SELECTED EDITED COMMENTS

- Materials will cost more.
- OE source provided information that 125 pounds of weight savings would yield a reduction in fuel consumption of 0.4 mpg.
- This price is application specific (vehicle/architecture); and it depends whether the proposed premium material is on the front-end, mid-section, or rear-end of the vehicle and where the vehicle is relative to its TWC maximum limit.
- While OEMs may claim that they will pay a premium for lighter parts, the truth is that they want to lower costs more.
- Without a weight-class change, there is little value to weight savings today. The assumption is that customer fuel becomes more important than CAFE in 2009, so the value increases. (Two other similar comments.)

RESULTS SUMMARY

Panelists note that the current value of a pound of weight saved on a vehicle is $1.00. This is forecast to increase to $1.50 in 2004 with no change in CAFE standards. This value is forecast to increase in 2009 to $2.00 at a CAFE of 30 mpg and to $3.00 at a CAFE of 35 mpg.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences 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 with the previous three surveys in the following table.

VALUE OF A POUND OF WEIGHT SAVINGS (1999 DOLLARS)								
FUEL ECONOMY	MEDIAN RESPONSE							
	1994 DELPHI VII		1996 DELPHI VIII		1998 DELPHI IX		2000 DELPHI X	
	FOR YEAR	$/LB.	FOR YEAR	$/LB.	FOR YEAR	$/LB.	FOR YEAR	$/LB.
CURRENT 27.5 MPG	1993	2.26	1995	1.10	1997	1.04	1999	1.00
FUTURE 27.5 MPG	1998	2.26	2000	1.10	2002	1.30	2004	1.50
30 MPG	2003	3.40	2005	2.20	2007	2.60	2009	2.00
35 MPG	2003	4.53	2005	3.21	2007	4.16	2009	3.00

Results from the current survey are similar to the past two surveys, but assign a significantly lower value on a pound of weight saved than the 1994 Delphi VII forecast.

Panelists forecast that the value of a pound of weight saved will increase by 2004, even without a change in CAFE standards. This finding is similar to that of Delphi IX, but is different than forecasts from Delphi VII and VIII. This may be a result of the forecast for higher fuel prices in 2004, or the expectation that CAFE will increase soon after 2004.

STRATEGIC CONSIDERATIONS

Panelists forecast that manufacturers will pay higher amounts in future years to reduce vehicle weight if CAFE increases. Weight reduction is certainly an effective method of increasing fuel-economy. However, other approaches such as improving powertrain efficiency may prove more cost effective in the long run. If CAFE is increased to 35 mpg, all possible tools for fuel-economy improvement will need to be utilized.

One of the panelists noted that manufacturers claim to be willing to pay for weight reduction, but when it comes down to actually doing it, cost wins out over weight. This will continue to be a very difficult trade-off if CAFE standards remain fixed. For light trucks, this trade-off may be more readily accepted because of the fact that domestic manufacturers are barely meeting current CAFE standards and light trucks are highly profitable. It should be noted again that European and domestic manufacturers may be forced to add cost to the vehicle to reduce weight, whereas Japanese manufacturers may not need to do so because of their favorable CAFE position.

In the current and past surveys, panelists comment that whether or not the weight savings will put a vehicle into a lower test-weight class affects the value of weight savings. Manufacturers often do not know within one test-weight class early in the design what the final weight of a new vehicle will be. It is therefore impossible when initiating individual component design to know whether or not saving a pound or ten on a given component will affect the test-weight class. Moreover, changes are often made during the development of the vehicle to fix durability problems. These changes usually add weight.

For a test weight-class 125 pounds wide, the best that can be said for saving a pound of weight is that there is a 1/125 chance that it will change the test weight class. Obviously a number of such changes increase the chances of a lower test weight class.

Many major components are used in a number of vehicle models. These include brakes, engines, transmissions, suspension systems, etc. Saving weight on one of these components will cause a test-weight change in some models, and will not change the test-weight class on others. The organization that decides that they are going to spend some

money over a large number of components is going to end up with a lighter vehicle that gets better fuel economy. This philosophy has been widely applied on engines, with aluminum replacing cast iron for cylinder heads and blocks.

Finally, it should be noted that weight savings may have a compounding effect. A lighter engine may allow the use of a lighter engine cradle. This may allow the use of smaller brakes and suspension components. It is important, therefore, to perform an analysis on the total vehicle when determining the benefit of weight reduction on an individual component. Many Japanese vehicles have benefited from the use of lightweight, high-performance powertrains. A vehicle designed to accommodate both a large and a small engine will not obtain optimal fuel economy with the small engine because most vehicle components are designed to carry the weight of the larger engine.

IV. BODY AND CHASSIS PRODUCT TRENDS

TECH-31 What percentage of North American-produced vehicles will have each of the following frame constructions in 2004 and 2009?

FRAME CONSTRUCTION	1998*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
PASSENGER CARS					
INTEGRAL BODY/FRAME OR UNIBODY	92.1	93	93	90/95	88/95
SEPARATE BODY/FRAME	4.8	3	2	2/4.9	1/4
SPACE FRAME	3.1	4	5	3/5	3/10
SPORT UTILITY VEHICLE					
INTEGRAL BODY/FRAME OR UNIBODY	24.5	30	35	25/30	28/45
SEPARATE BODY/FRAME	75.5	70	60	68/73.6	53.8/65
SPACE FRAME	0.0	0	1.5	0/2	0/5
MINIVAN					
INTEGRAL BODY/FRAME OR UNIBODY	n/a**	80	89	60/95	70/95
SEPARATE BODY/FRAME	n/a**	19.5	10	5/47.5	0/29
SPACE FRAME	n/a**	1	2	0/5	0/9

*Source: Ward's Automotive Reports, Jan. 18, 1999, and OSAT estimates.

**Baseline information not available.

SELECTED EDITED COMMENTS

- For passenger cars, small subframes, such as a front engine-cradle and a rear suspension member, are considered integral body/frame types.
- I would expect some BFI/space frame "hybrids" to start emerging. I would also expect to see some lighter-duty trucks/hybrids/SUVs moving toward the more mass efficient BFI-type construction versus body-on-frame.
- In order to improve NVH, luxury cars with frames will return somewhat, but in ten years they will again have to abandon them for weight purposes.
- Many will have subframes for noise isolation and easier platform utilization.
- Plastic bodies bonded to aluminum frames (cars, SUVs minivans).
- The distinction between passenger cars, SUVs, and minivans will begin to blur, making it difficult to make a clear prediction.

RESULTS SUMMARY

Panelists forecast that the frame design on passenger cars will be basically unchanged in the next decade. Both sport utility vehicles and minivans are forecast to see an increase in the use of integral body/frame or unibody by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

Minivans were not covered in previous Delphi forecasts. The current survey is in good agreement with past surveys for passenger cars and sport utility vehicles.

STRATEGIC CONSIDERATIONS

Integral body/frame is the dominant design for passenger cars. Considerable weight savings have been realized relative 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 manner similar to passenger cars. It is reasonable to assume that these vehicles will become more like passenger cars in the future, particularly the smaller sport utility vehicles that are already being introduced in increasing numbers. Many future SUV programs are aimed at using passenger car (unibody) platforms. Therefore, in addition to lighter vehicle designs, these vehicles will require improved ride and handling. The larger SUVs will likely retain the separate body frame and its inherent ability to handle great loads.

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. The Saturn is further differentiated from most other vehicles by the use of plastic body panels. The space frame, while limited in this and past forecasts, just won't go away.

TECH-32 What percentage of North American-produced passenger cars currently incorporate the following suspension features and what will the percentage be in 2004 and 2009? Please provide your estimate for current vehicles.

SUSPENSION FEATURES	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST.	2004	2009	CURRENT EST.	2004	2009
	(%)	(%)	(%)	(%)	(%)	(%)
FRONT SUSPENSION CONFIGURATION						
MACPHERSON STRUTS	80	75	75	75/80	70/80	70/75
TWIN A-ARM	20	25	25	20/25	20/25.8	21.3/30
REAR SUSPENSION CONFIGURATION						
INDEPENDENT	60	65	70	52.5/61	60/70	61.3/75
NON-INDEPENDENT	40	31.5	25	30/40	27.8/35	20/30
SELF LEVELING	8	10	15	5/10	8/15	10/20
SPRINGS						
AIR	5	5	5	3/5	4/6.8	5/8.8
COMPOSITES	2	5	9	2/3	3/5.8	5.3/10
OIL/FLUID	2	3	5	1/ 2	2/5	3/6
STEEL	91	86.5	80	90/93	82/90	75/85

OTHER RESPONSES

- Springs-polymer. Current: 2%; 2004: 8%; 2009: 10%
- Multilink front suspension. Current: 0%; 2004: 10%; 2009: 20%

SELECTED EDITED COMMENTS

- I don't know the specific execution alternatives, but in general there will be a trend towards better/more sophisticated suspension systems.
- Some potential exists for composites due to mass and packaging advantages.
- Twin A-arm suspension use will increase for two reasons: 1) better ride and handling on front-drive cars and 2) continued cost pressures will result in fewer standard self-leveling systems.

RESULTS SUMMARY

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

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

Rear suspensions: The use of independent rear suspensions will increase to 70 percent in 2009 from 60 percent currently.

Self-leveling: Penetration is forecast to increase to 15 percent by 2009 from 8 percent currently.

Springs: Steel springs will continue to dominate, but the use of composites and oil/fluid springs will increase.

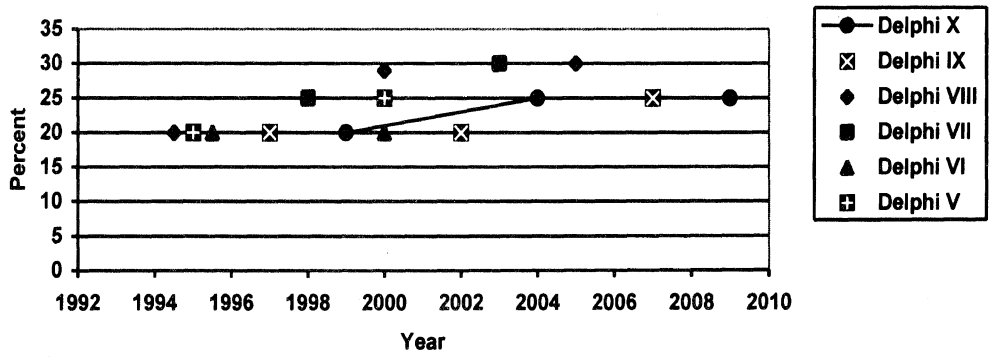
MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

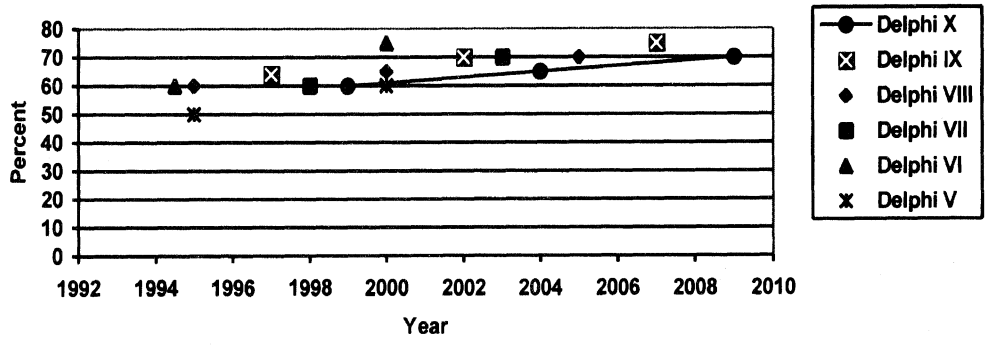
Results from the current survey are compared with those of past surveys in the following graphs:

Twin A-arm Front Suspension



The forecast increased penetration of twin A-arms from some earlier Delphi surveys has not occurred. The 1992 Delphi VI survey did forecast no change in penetration through the year 2000, however.

Independent Rear Suspension Forecast
North American Car Production



The current forecast for independent rear suspensions is in general agreement with previous forecasts, but a bit on the low side.

The current forecast is in general agreement with past forecasts with regards to springs and self-leveling.

STRATEGIC CONSIDERATIONS

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.

Twin A-arms and independent rear suspensions are forecast to increase in use. The ride and handling benefits of these systems must be weighed against increased cost for each application.

Composite springs are attractive for their weight-savings potential but, again, must pass the test of cost. The other alternative to steel presents some advantages or they would not be considered at all. Still, it appears that breakthroughs are required for penetrations to expand significantly.

TECH-33 What percentage of North American-produced passenger cars will have each of the following chassis/suspension features in 2004 and 2009? Please provide your estimate for current vehicles.

CHASSIS/SUSPENSION FEATURES	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST.	2004	2009	CURRENT EST.	2004	2009
RIDE/HANDLING						
PASSIVE CONTROL (PRESENT SYSTEM)	95	90	85	90/98	80/95	70/95
PASSIVE-DRIVER SELECTED	3	5	10	1.8/5	3.5/15	5/20
SPEED-SENSITIVE POWER STEERING	15	20	30	5/25	15/32.5	17.5/45
NON-POWER STEERING	10	5	3.5	2.5/10	1/10	0/5
POWER STEERING						
ELECTRICAL WITH ELECTRONIC CONTROL	1	10	20	0/5	3/15	10/30
HYDRAULIC WITH ELECTRONIC CONTROL	8.5	15	15	2.3/14	5/25.8	10/31.3
TRADITIONAL HYDRAULIC	87	72	55	75/93.8	57.5/85	40/73.5

OTHER RESPONSES

- Chassis: Adaptive. Current: 0%; 2004: 0%; 2009: 15%
- Ride: Active. Current: 1%; 2004: 1%; 2009: 2%
- Ride: Smart. Current: 0%; 2004: 1%; 2009: 5%

SELECTED EDITED COMMENTS

- Cost, reliability, and lack of "real added value" will hold back ride controls but not stability controls that potentially could have a "very large" added value to the consumer. EPS will gain momentum for fuel economy as costs fall.
- Electronic control will benefit fuel economy

RESULTS SUMMARY

Panelists forecast that passive-driver-selected suspension systems will be installed on 10 percent of passenger cars by 2009. In the same time frame, speed-sensitive power steering is forecast for 30 percent of passenger cars. Electric power steering with electronic control is forecast for 20 percent, and hydraulic power steering with electronic control on 15 percent of passenger cars. Nonpower steering is forecast to decrease to 3.5 percent in 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

CHASSIS/SUSPENSION FEATURE	MANUFACTURER MEAN	SUPPLIER MEAN
RIDE/HANDLING		
PASSIVE-DRIVER SELECTED 2004	7.1	12.7
PASSIVE-DRIVER SELECTED 2009	11.3	20.4
STEERING		
TRADITIONAL HYDRAULIC CURRENT	87.2	76.7

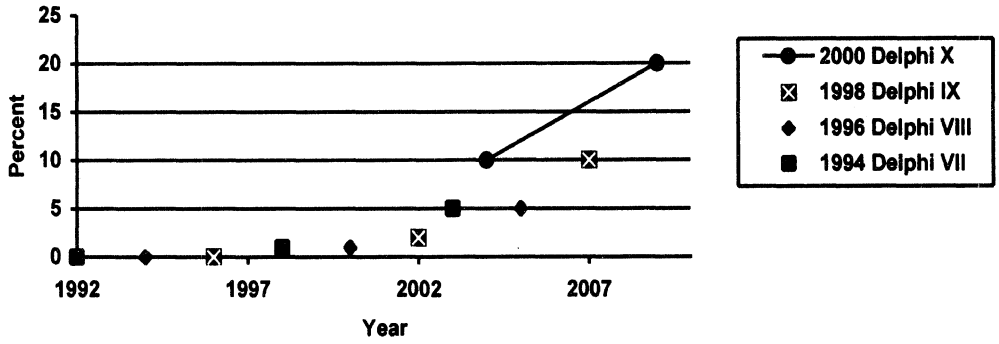
Suppliers forecast a higher use of passive-driver selected suspension than do manufacturers. Manufacturers forecast greater use of the traditional hydraulic steering than do suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

There is good agreement between the current survey and past surveys on ride/handling systems, speed-sensitive power steering, and hydraulic power steering with electronic control.

The forecast for electric/electronic power steering in the current survey is higher than that of past surveys, as shown in the following graph.

Electric/Electronic Power Steering



STRATEGIC CONSIDERATIONS

High cost may continue to limit advanced suspension systems. Driver-selected-passive suspensions are forecast to increase penetration to 10 percent by 2009, however. This feature allows the driver to select a soft ride for highway cruising, or a stiffer suspension for winding roads and reduced sway on corners. Electronic (smart) suspensions seem to be at the threshold of major growth and could markedly change our entire concept of suspension controls.

Electronic control of hydraulic steering provides modification to steering effort based on vehicle speed or driver preference.

Electric power steering provides low power consumption, which is an advantage for fuel economy and could amount to as much as a mile per gallon improvement. There may be driving-feel benefits as well. Alternator capacity may be a limiting factor in some applications.

TECH-34 What percentage of domestic and imported North American-produced passenger cars and light trucks will have the following technologies in 2004 and 2009?

TECHNOLOGY	1998* (%)	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004 (%)	2009 (%)	2004 (%)	2009 (%)
PASSENGER CAR					
ACTIVE/SEMI-ACTIVE ENGINE MOUNT	n/a**	5	10	2/5	5/15
ANTILOCK BRAKE SYSTEM	59.2	70	80	65/75	75/90
FOUR-WHEEL DISC BRAKES	7.3	10	20	10/15	15/30
TRACTION (ANTISPIN) CONTROL	20.2	30	40	25/35	30/50
"YAW" OR STABILITY CONTROL	<1.0	4	7	1.3/5	4/15
LIGHT TRUCK					
FOUR-WHEEL ANTILOCK BRAKES	67.2	75	85	70/80	80/90
FOUR-WHEEL DISC BRAKES	n/a**	10	20	5/20	9.5/32.5
TWO-WHEEL ANTILOCK BRAKES	24.6	20	14	15/28	7.3/25

*Source: Ward's Automotive Reports, Dec. 28, 1998 and Feb. 1, 1999.
**Baseline information not available.

SELECTED EDITED COMMENTS

- Fuel cells and hybrid vehicles will make obsolete or reduce the active-engine-mount requirements.

RESULTS SUMMARY

Panelists forecast that a four-wheel antilock brake system will be installed on 80 percent of passenger cars and 85 percent of light trucks by 2009. Four-wheel disc brakes are forecast on 20 percent of passenger cars and light trucks in the same timeframe. Traction control is forecast for 40 percent of passenger cars, nearly double the current rate.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

TECHNOLOGY	MANUFACTURER MEAN	SUPPLIER MEAN
LIGHT TRUCK		
TWO-WHEEL ANTILOCK BRAKES 2009	13.8	24.3

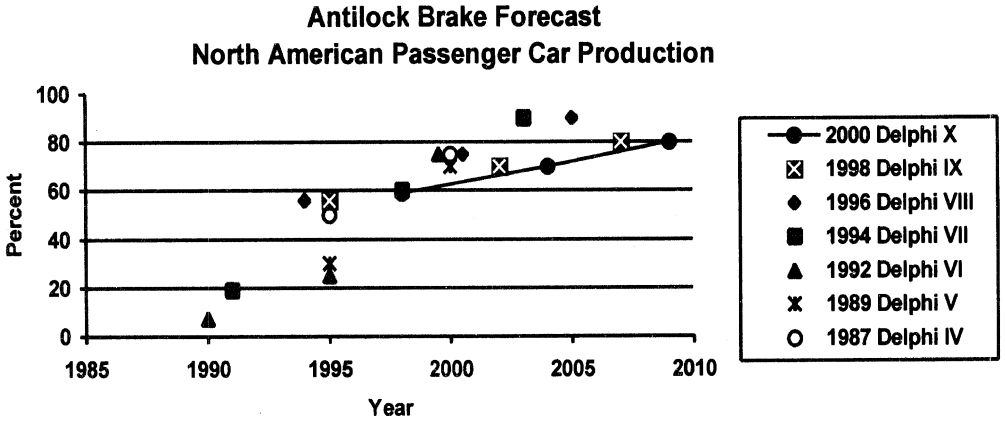
Suppliers forecast a greater use of two-wheel antilock brake systems in 2009 on light trucks than do manufacturers.

TREND FROM PREVIOUS DELPHI SURVEYS

Active/semiactive engine mounts were not covered in this format in previous surveys.

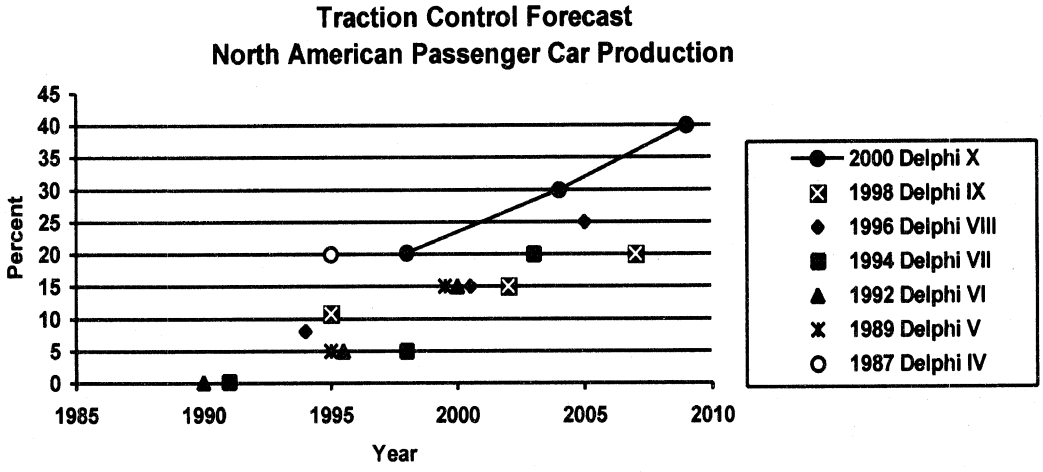
The forecast for yaw control in the current survey is in agreement with the results of Delphi IX, which was the first survey to cover this technology.

Results for braking systems from the current survey are compared to those of previous surveys in the following graphs.

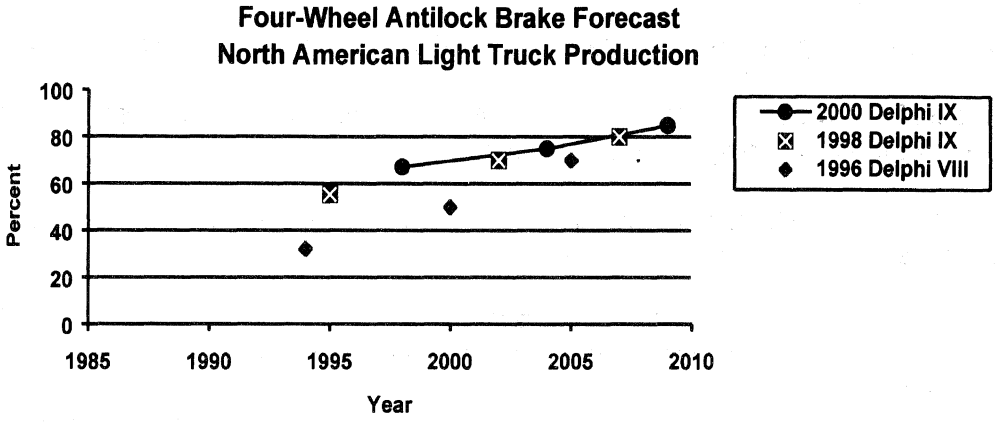


Results for the current survey for antilock brakes are in agreement with the most recent forecast, Delphi IX, except it forecasts a lower penetration in the 2005 to 2010 time frame than some earlier forecasts.

The current forecast is in general agreement with past forecasts for four-wheel disc brakes.



The Delphi X forecast for traction control is somewhat higher than past forecasts.



The forecasts of the current survey are similar to those of previous surveys for the long term (2009), but a bit higher in the short term.

STRATEGIC CONSIDERATIONS

The cost of active/semiactive engine mounts will probably limit the application of this technology to upscale vehicles. It is likely, therefore, that penetration will not exceed the long-term forecast of 10 percent.

Customers recognize the benefits of antilock braking systems, and are purchasing this feature in increasing numbers. This feature is standard equipment on a number of models in the industry, and the penetration is forecast to increase. There have been some questions raised regarding the safety record of vehicles with this feature. Customers, particularly in northern climates, appreciate the superior braking control obtained with antilock brakes but must learn how to use them properly.

The application of traction control is forecast to markedly increase in the next decade. This feature is found in a number of variants in the industry. A low-cost version simply reduces engine power when wheel slip is observed. More sophisticated, and costly, versions also apply braking to individual slipping wheels. The widespread application of antilock brakes has made this feature a relatively inexpensive add-on feature. Traction control has the most effect on rear-wheel drive vehicles. Although this feature does improve traction in icy conditions, four-wheel drive is still a much more effective and costly system.

Yaw control is a feature that will be seldom activated on a vehicle, particularly for drivers that are not aggressive; but it is truly a sensational feature when facing an impending skid. Because of increased cost this feature will likely be applied to upscale image vehicles in the near term. Considering the cost reductions seen with such features as air bags and ABS, the cost of YAW control could be reduced markedly.

An important, relatively new trend is the growth in four-wheel disk brakes in light trucks. The new GM pickup trucks offer this feature and may spur rapid movement to this technology.

TECH-35 What percentage of North American-produced passenger cars will incorporate the following tire features in 2004 and 2009?

TIRE FEATURES	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004 (%)	2009 (%)	2004 (%)	2009 (%)
AIRLESS SPARE	5	10	2/10	5/30
FAILURE SENSING DEVICES/LOW PRESSURE WARNING	10	20	5/10	10/40
NO SPARE TIRE FOR VEHICLE	5	20	1/10	5.3/40
PUNCTURE RESISTANT/SELF-SEALING	10	20	5/20	10/30
RUN-FLAT	10	30	5/15	20/40

SELECTED EDITED COMMENTS

- Better *run flat* tires will evolve and manufacturers will rush toward them for mass reduction and packaging-space enhancement as they improve in ride quality, cost, and rolling resistance.
- The desire for increased safety and security will drive significant change in this area.

RESULTS SUMMARY

An airless spare tire is forecast for 10 percent of passenger cars by 2009. In the same time frame, 20 percent of passenger cars are forecast to have failure sensing devices/low-pressure warning, no spare tire for vehicle, puncture-resistant/self-sealing and run-flat tires.

MANUFACTURER/SUPPLIER COMPARISON

The statistically significant differences in responses between manufacturers and suppliers are shown in the following table.

TIRE FEATURES	MANUFACTURER MEAN	SUPPLIER MEAN
AIRLESS SPARE 2004	6.6	13.8
FAILURE-SENSING DEVICES/LOW-PRESSURE WARNING 2009	33.2	21.6

TREND FROM PREVIOUS DELPHI SURVEYS

The current survey is in agreement with past surveys for airless spare and puncture-resistant/self-sealing tires. For the remaining features, past surveys forecast 10 percent penetration in 10 years, whereas the current survey forecast 20-30 percent for these features.

STRATEGIC CONSIDERATIONS

There is considerable incentive to eliminate the spare tire from the vehicle. Included in these incentives are weight and cost reduction and increased package space. In order to eliminate the spare tire, however, manufacturers must prove to customers that the alternatives such as

run-flat tires are reliable and will allow the driver to safely drive long distances on the flat tire to reach safety a facility to repair the tire.

The spare tire was eliminated on the 1998 Corvette. Tire manufacturers are producing run-flat tires. These moves are the beginning of the forecast for a meaningful move to vehicles without spare tires.

It should be noted that the interquartile range is wide for responses to this question. This is an indication of uncertainty or differences in strategy on the part of manufacturers.

V. SAFETY ISSUES

TECH-36 What percentage of North American-produced passenger cars and light trucks will incorporate rear seat, side, roof-rail and knee bolster airbags in 2004 and 2009?

AIRBAG APPLICATIONS	1998* (%)	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004 (%)	2009 (%)	2004 (%)	2009 (%)
PASSENGER CARS					
KNEE BOLSTER	0	2	5	0/5	2/11.3
REAR SEAT OCCUPANTS	0	2	5	0/5	3.3/16.5
ROOF-RAIL	n/a**	5	10	1.3/10	5/20
SIDE	6.4	15	35	10/30	15/50
LIGHT TRUCKS					
KNEE BOLSTER	0	0	5	0/5	0/10
PASSENGER SIDE	37.1	50	90	50/60	70/100
REAR SEAT OCCUPANTS	0	0	1	0/5	0/10
ROOF-RAIL	n/a**	3	6	0/5	1/20
SIDE	3.6	10	20	5/23.8	10/50

*Source: Ward's Automotive Reports, Dec. 28, 1998, Feb. 1, 1999, and OSAT estimates.
**Baseline information not available.

SELECTED EDITED COMMENTS

- Barring any legislation.

RESULTS SUMMARY

Panelists forecast limited use of knee-bolster, rear-seat-occupant and roof-rail airbags in the next decade on both passenger cars and light trucks. Passenger-side airbags are forecast for 90 percent of light trucks by 2009. In the same timeframe, side airbags are forecast for 35 percent of passenger cars and 20 percent of light trucks.

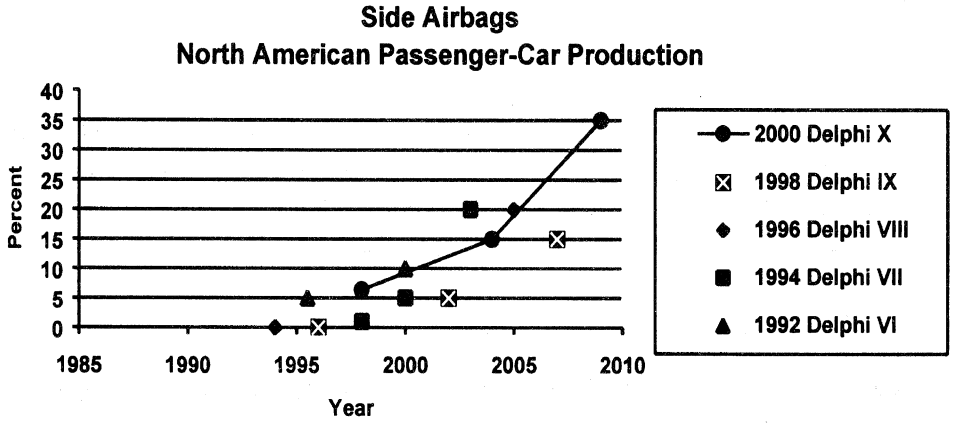
MANUFACTURER/SUPPLIER COMPARISON

There are statistically significant differences in responses between manufacturers and suppliers for the items shown in the following table.

AIRBAG APPLICATIONS	MANUFACTURER MEAN	SUPPLIER MEAN
PASSENGER CARS		
KNEE BOLSTER 2009	17.9	8
ROOF-RAIL 2004	11.4	3.6
ROOF-RAIL 2009	28.3	8.6
SIDE 2004	27.1	15.1
SIDE 2009	46.9	31.5
LIGHT TRUCKS		
KNEE BOLSTER 2009	13.2	4.8
PASSENGER SIDE 2004	65.6	52.2
ROOF-RAIL 2004	9.9	3.1
ROOF-RAIL 2009	21.7	7.2
SIDE 2004	19.1	11.9
SIDE 2009	42.9	24.5

TREND FROM PREVIOUS DELPHI SURVEYS

Roof-rail airbags were not covered in a previous Delphi forecast. There is generally good agreement between the current and past surveys for the remaining features. The following graph for passenger-car side airbags shows the forecast increase in the next decade compared with previous surveys.



STRATEGIC CONSIDERATIONS

Panelists forecast an expansion of the number and types of airbags for both passenger cars and light trucks. The concern over the danger that airbags may present to children and small drivers does not outweigh the benefits of airbags. Certainly many lives have been saved because of the presence of airbags.

Airbags provide the greatest benefit to an unbelted occupant. There is some benefit to belted occupants, however, particularly at high vehicle speeds. Airbags are known to produce some injuries to belted occupants at low vehicle speeds, which would not have occurred without the airbag. The overall benefit of airbags appears to outweigh the known deficiencies. The safest vehicle driver or occupant is certainly one that is belted and in a vehicle with an airbag.

Recycling vehicles with airbags will become an increasing problem, as airbag actuators must be deactivated prior to recycling.

Manufacturers forecast higher use of most airbag features than do suppliers. The reason for the discrepancy between manufacturers and suppliers regarding airbag use is not clear. It is possible that manufacturers have not communicated their expectations and forecast plans to suppliers. It is also possible that suppliers are more pessimistic regarding the application of additional airbag features because of the controversy over airbag safety. This is particularly true for safety related to children and small adults. It appears that improved communication between manufacturers and suppliers in this area is required.

The emergence of "smart" airbags appears to be on the horizon, and manufacturers are beginning to introduce rudimentary variations. The technical challenges are formidable but not insurmountable. There is intense activity on this technology throughout the industry.

TECH-37 What percentage of passenger cars produced in North America will have the following vehicle systems by 2009?

VEHICLE SYSTEMS	MEDIAN RESPONSE	INTERQUARTILE RANGE
	2009 (%)	2009 (%)
ADAPTIVE CRUISE CONTROL	15	10/30
ADJUSTABLE PEDALS	20	5/30
AUTOMATIC TOLL COLLECTION	10	5/25
COLLISION WARNING SYSTEMS	22.5	15/42.5
FRONT	10	5/25
REAR	10	5/25
BLIND SPOT	10	5/20
FOUR-POINT SEAT BELTS	5	1/10
GPS/CELLULAR-PHONE-BASED SAFETY SYSTEM (I.E., GM "ON-STAR" SYSTEM)	25	15/50
IN-VEHICLE MESSAGE SYSTEM	20	10/32.5
NAVIGATION SYSTEM	25	15/30

OTHER RESPONSES

- Geriatric owner/passenger aids. 2009: 10%
- Robotic refueling ready. 2009: 25%
- Steering/lane holding (lateral) controls. 2009: 5%
- Vision enhancement. 2009: 11%

RESULTS SUMMARY

Panelists forecast that several safety-related-emerging-vehicle systems will be installed in 10 to 25 percent of passenger cars by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers, with the exception of the items shown in the following table.

VEHICLE SYSTEMS	MANUFACTURER MEAN	SUPPLIER MEAN
ADJUSTABLE PEDALS	28.2	14.4
GPS/CELLULAR PHONE BASED SAFETY SYSTEM (E.G., GM "ON-STAR" SYSTEM)	35.3	25.4

Manufacturers forecast higher penetration of adjustable pedals and GPS/cellular-phone-based safety systems than do suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

Adjustable pedals and four-point seat belts were not covered in a previous Delphi forecast. The current survey forecasts higher penetration of other systems (with the exception of automatic toll collection) than previous forecasts. This is shown in the following table.

VEHICLE SYSTEMS	MEDIAN RESPONSE			
	1994 DELPHI VII FOR THE YEAR 2003 (%)	1996 DELPHI VIII FOR THE YEAR 2005 (%)	1998 DELPHI IX FOR THE YEAR 2007 (%)	2000 DELPHI X FOR THE YEAR 2009 (%)
ADAPTIVE CRUISE CONTROL	5	10	10	15
COLLISION WARNING SYSTEMS	8	5	10	22.5
AUTOMATIC TOLL COLLECTION	5	6	10	10
NAVIGATION	5	10	10	25
IN-VEHICLE MESSAGE SYSTEM	10	10	18	20

STRATEGIC CONSIDERATIONS

The vehicle systems addressed in this question will likely appear first in luxury vehicles, although there are some exceptions. For example, Ford introduced a rear-collision warning in their Windstar minivan. As use increases in luxury vehicles and designs improve, system costs will decrease. At some point, some or all of the systems may gain wide acceptance in family passenger cars, as well. 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.

Adjustable pedals allow the driver better access to the accelerator and brake pedal. This improved access may allow quicker response in an emergency situation. In addition, adjustable pedals allow a small driver to sit farther from the steering wheel, an important factor in safe airbag deployment.

The GPS/Cellular, (in which message and navigation systems, perhaps combined in a single system), may be at the threshold of an explosion in use. The key issue is the cost/value trade-off. The potential for innovation and creativity in this area is significant.

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VI. POWERTRAIN AND DRIVETRAIN

TECH-38 What percentage of North American-produced passenger-car and light-truck engines will be equipped with the following number of cylinders in 2004 and 2009?

PASSENGER-CARS NUMBER OF CYLINDERS	1998*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
3	0.2	0.5	1	0.2/1	0.2/2
4	52.1	52.1	54	50/55	50/60
6	38.6	38.6	38.5	35/40	32.8/41
8	9.1	8	7	5/10	5/10

LIGHT TRUCKS NUMBER OF CYLINDERS	1998*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
4	10.8	11	12	10/12.9	10/15
6	51.3	52.3	52.5	50/55	50/59.8
8	37.6	35.3	35	34/39.9	30/38
10/12	0.4	0.5	1	0.2/1	0/1

*Source: Ward's Automotive Reports, Jan. 25, 1999 and December 21, 1998.

SELECTED EDITED COMMENTS

- For three-cylinder passenger-cars, this would seem to be very dependent on the success manufacturers have in introducing hybrid electric vehicles that only need a small second power source (engine).
- The desire for power won't go away. The need for cleaner engines may drive engine design to larger, more lightly loaded designs.
- The growing number of crossover vehicles and small vans classified as trucks will increase the four-cylinder penetration for trucks.
- Unless there is another energy crisis, the mix shouldn't change much.

RESULTS SUMMARY

Panelists forecast that the number of cylinders in an engine will be nearly unchanged over the next decade. Four-cylinder engines are forecast in more than half of passenger-cars and six-cylinder engines in more than half of light trucks. Panelists forecast a small decrease in the number of eight-cylinder engines and a small increase in the number of four-cylinder engines.

MANUFACTURER/SUPPLIER COMPARISON

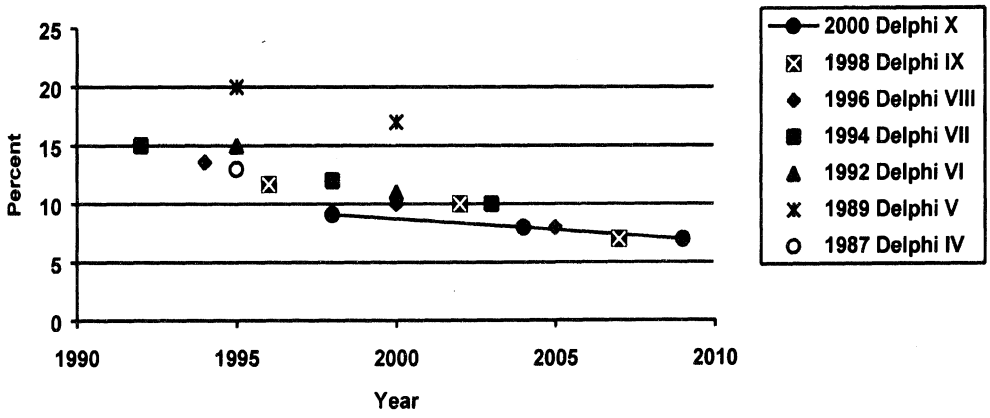
There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

2004 PASSENGER-CARS NUMBER OF CYLINDERS	MANUFACTURER MEAN	SUPPLIER MEAN
8	9	7.7

TREND FROM PREVIOUS DELPHI SURVEYS

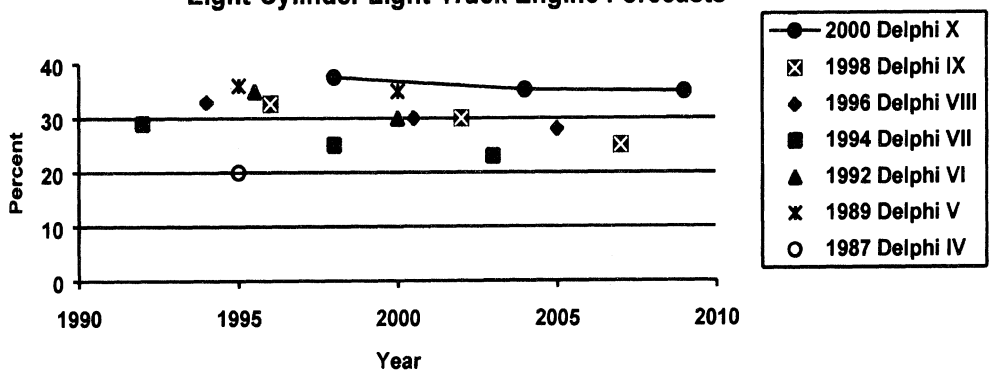
Results from the current survey are in general agreement with those of past surveys. The trend for eight-cylinder engines for passenger-cars and light trucks is shown in the following graphs.

Eight-Cylinder Passenger-Car Engine Forecasts



The decrease in the number of eight-cylinder engines in passenger-cars forecast in earlier surveys has occurred, and the trend continues.

Eight-Cylinder Light-Truck Engine Forecasts



In each of the past four Delphi forecasts, the penetration of eight-cylinder engines in light trucks has been forecast to decrease. In fact, the actual penetration has actually increased in the base year for each of the last four forecasts.

STRATEGIC CONSIDERATIONS

The decrease in eight-cylinder engines in light trucks forecast in this and previous Delphi forecasts has not come to pass. This is likely a result of continued low fuel prices and stable CAFE standards. The demise of large eight-cylinder passenger-cars has probably shifted some eight-cylinder demand to light trucks. Many vehicle owners who pulled trailers or boats with a passenger-car are now buying light trucks for that purpose. In most of these applications, an eight-cylinder engine will be the engine of choice.

The forecast for decreasing eight-cylinder engine use is compatible with the increase in CAFE and gasoline prices forecast in earlier questions.

One thing is clear, the past and expected future shifts in engine-cylinder numbers is gradual, both due to the gradual shift in vehicle-platform configurations and the high cost and complexity of new engine progress.

TECH-39 What percentage of six-cylinder engines in North American-produced passenger-cars and light trucks will be 60 degree V6, 90 degree V6 and In-line (IL 6)?

SIX-CYLINDER ENGINES	1998* (%)	MEDIAN RESPONSE 2004 (%)	MEDIAN RESPONSE 2009 (%)	INTERQUARTILE RANGE 2004 (%)	INTERQUARTILE RANGE 2009 (%)
PASSENGER-CARS					
60° V6	68.7	70	72.5	69.8/70	68.8/80
90° V6	30.6	30	25	28/30	20/30
IL 6	<1.0	1	1	0/1.3	0/2.3
LIGHT TRUCKS					
60° V6	47.6	50	51	47.7/51	48.3/60
75° V6	3.8	4	4	2/5	2/5
90° V6	35.2	35	31	30/37.5	26/38
IL 6	13.5	12	10	10/15	7/16.5

*Source: Ward's Automotive Reports, December 21, 1998 and Jan. 25, 1999; Automotive Industries Engine Insert, March 1998.

SELECTED EDITED COMMENTS

- As new engine series come on line, the old 90 degree V6 and IL 6 families will disappear.
- Crush space will continue to constrain IL 6's in cars. Sixty degree versus 90-degree V6 will be a "tradeoff" of crush space versus hood height versus manufacturing flexibility with V8's. Might see a few more "narrower" V6's like the 15-degree VW V6 and 54-degree OPEL V6 emerge, but 60 degrees will likely be the configuration of choice for TFWD vehicles.
- Small sport utilities will drive compact, i.e., 60 degree and better packaging also favors them in passenger-cars.

RESULTS SUMMARY

Panelists forecast that the 60-degree configuration will be used in 72.5 percent of passenger-car six-cylinder engines and in 51 percent of light truck six-cylinder engines.

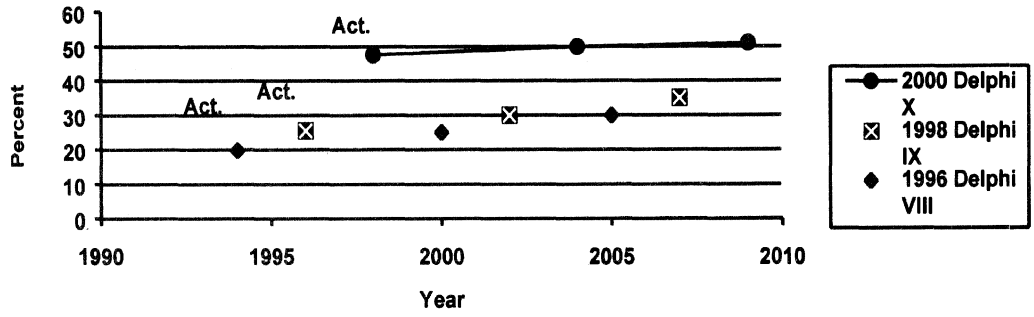
MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

For passenger-car engines, the results of the current survey are in agreement with previous surveys. For light trucks, the move to 60-degree V6 engines has progressed at a rate greater than forecast. This is shown in the following graph.

60-Degree V6 Light Truck Engine Forecasts



The actual penetration of 60-degree V6 engines in light trucks was higher in 1998 than forecast by previous surveys.

STRATEGIC CONSIDERATIONS

The primary advantage of the IL 6 design is outstanding balance characteristics. Cost is also an advantage, depending on the valvetrain configuration. Multivalve (three and four valve) designs are far less expensive for in-line rather than V-designs where more camshafts are required. 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. This limitation is not as significant for light trucks. Several manufacturers are tooling in-line sixes for light trucks.

The superior balance characteristics of the 60-degree V6 as compared to the 90-degree V6 are the primary reason for the trend towards 60-degree designs. A balance shaft is required in a 90° V6 to provide satisfactory smoothness at low speeds. This adds cost, weight, and complexity to the engine that is not required with the 60-degree V6 design.

For vehicle packaging considerations, the lower profile of the 90-degree engine allows a lower hood line, whereas engine width is increased.

TECH-40 What percentage of North American-produced passenger-car engines will incorporate the following number of valves per cylinder in 2004 and 2009?

VALVE CONFIGURATIONS	1998* (%)	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004 (%)	2009 (%)	2004 (%)	2009 (%)
TWO VALVES PER CYLINDER	60.9	55	50	50/56	35.3/50
THREE VALVES PER CYLINDER	0.0	2	4.5	0/5	0/10
FOUR VALVES PER CYLINDER	39.1	45	50	40.3/45	44.3/58.8
FIVE VALVES PER CYLINDER	0.0	0	0	0/1	0/1.3

*Source: Ward's Automotive Reports, Dec. 21, 1998 and Automotive Industries Engine Insert, Mar. 1998.

SELECTED EDITED COMMENTS

- I don't know the specifics but the trend is away from two valves per cylinder to three or more valves per cylinder
- If three works as well as four, then the cheaper valvetrain will prosper.
- Pushrod (ohv) 2V engines still deliver good package size and value and will likely enjoy a long "old age" before they expire from the market. The three-valve may offer both power and an emissions advantage.
- Three valve increase for direct injection applications.

RESULTS SUMMARY

Panelists forecast that four-valve-per-cylinder engine penetration will increase somewhat and two-valve-per-cylinder engines will decrease a bit in the next decade. Each is forecast to share half of the market by 2009.

MANUFACTURER/SUPPLIER COMPARISON

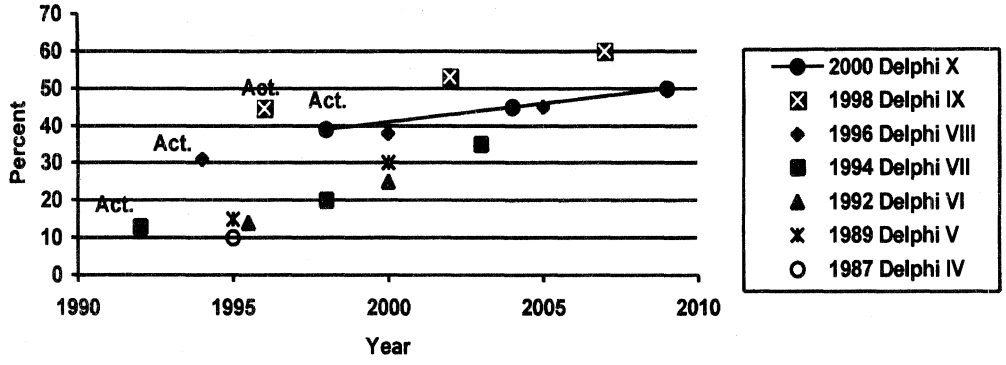
There are no statistically significant differences in responses between manufacturers and suppliers, with the exception of the item shown in the following table.

VALVE CONFIGURATIONS	MANUFACTURER MEAN	SUPPLIER MEAN
TWO VALVES PER CYLINDER 2009	39.1	46.7

TREND FROM PREVIOUS DELPHI SURVEYS

The current forecast for four-valve-per-cylinder engines is compared with that of previous forecasts in the following graph.

Four-Valve-per-Cylinder Engine Forecasts
North American Passenger Car Production



The penetration of four-valve-per-cylinder engines has increased at a rate greater than forecast in early surveys.

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 the weight of a four-valve-er-cylinder engine. Furthermore, 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 come to pass. 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 marked decrease in two-valve engines in the next decade, however.

Certainly, a key factor in valvetrain configuration will be future emission standards. In general, multivalve designs enable an improved combustion-chamber design for emissions control.

TECH-41 What percentage of North American-produced passenger-car engines will utilize the following valvetrain configurations in 2004 and 2009?

VALVETRAIN CONFIGURATIONS	1998*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
IN-LINE ENGINE CONFIGURATIONS					
DUAL OVERHEAD-CAM	46.5	50	51	47.4/51	49/68.5
PUSH-ROD	7.9	5	3	4/7	0/5
SINGLE OVERHEAD-CAM	45.6	45	44.5	42.8/48.5	39.8/50
V ENGINE CONFIGURATIONS					
DUAL OVERHEAD-CAM	28.3	32.3	36.5	30/40	32/50
PUSH-ROD	55.5	50	40	40/52	20/45
SINGLE OVERHEAD-CAM	16.2	20	21.5	15.8/22.6	16.2/30

*Source: Ward's Automotive Reports, Dec. 21, 1998, and Automotive Industries Engine Insert, Mar. 1998.

SELECTED EDITED COMMENTS

- Electric camless valve actions will be introduced before 2004. They may increase to 10 percent in 2009.
- SOHC has packaging advantage in V engine configurations.
- The old pushrod designs will linger, but they are on their way out.

RESULTS SUMMARY

Panelists forecast that dual-overhead-cam and single-overhead-cam configurations will be used in similar numbers (51 and 44.5 percent) on in-line engine configurations in 2009. For V engine configurations, push-rods are forecast to be used in 40 percent of engines, greater than that of either dual-or single-overhead-cam designs, but considerably below the current level.

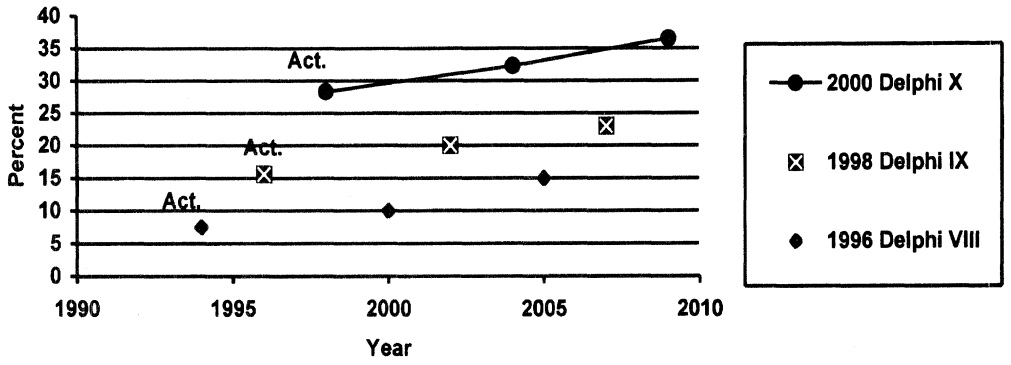
MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

There is general agreement between the current and previous surveys, with the exception of a higher forecast for dual-overhead-cam engines and a lower forecast for push-rod V engines. A comparison of the current and previous two Delphi forecasts for dual overhead-cams in V engines is shown below.

Dual Overhead Cam in V Engine Configurations
North American Passenger-Car Production



The actual increase in penetration of dual-overhead-cam V engines has exceeded that of previous forecasts.

STRATEGIC CONSIDERATIONS

Overhead-cam engines generally allow optimal 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. 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 higher stress levels, thereby allowing a more rapid acceleration of the valve.

Dual-overhead camshafts add significant weight and bulk 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 with 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 their 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.

Tougher emission standards in the future could have an impact on valvetrain configuration because of their effect on combustion-chamber characteristics and other factors. This may accelerate the move to overhead-cam engines. The fact that the actual application rate of dual-overhead-cam engines has exceeded previous forecasts may be a reflection of this design consideration.

TECH-42 What percentage of North American-produced passenger-car engines currently incorporate the following technical features, and what will the percentage be in 2004 and 2009? Please provide your estimate for current vehicles.

ADVANCED ENGINE FEATURES	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST.	2004	2009	CURRENT EST.	2004	2009
	(%)	(%)	(%)	(%)	(%)	(%)
BALANCE SHAFT (% OF FOUR-CYLINDER ENGINES)	25	30	40	20/25	30/35	35/45
BALANCE SHAFT (% OF 90° SIX-CYLINDER ENGINES)	25	30	40	20/25	30/35	35/40
HOLLOW CAMSHAFT	10	15	30	5/10	12.8/20	20/30
LIGHTER VALVES (20% OR MORE)	5	10	20	5/5	10/15	15/28.8
POWDERED METAL CAM AND GEARS	10	20	30	10/10	15/25	20/35
ROLLER LIFTERS OR ROLLER FOLLOWERS						
% OF DOHC ENGINES	20	35	50	20/30	30/41.5	40/60
% OF PUSH-ROD ENGINES	45	45	50	35/50	40/50	35/55
% OF SOHC ENGINES	30	40	50	30/35	32.8/45	40/57.5
VARIABLE LIFT CONTROL	3	7	15	2/3	5/10	10/20
VARIABLE VALVE PHASING	3	10	16.5	2/5	5/14.3	10/24.3
VARIABLE VALVE TIMING CONTROL	5	15	25	4/5	10/15	20/33.8

SELECTED EDITED COMMENTS

- Fuel economy requirements on large engines will drive up the usage of VVT.
- These technologies will trend strongly towards standard fare in the future—especially the technologies that enable fuel economy, emissions, and performance. Cost is the constraining factor for the lower-end of the product portfolio.
- If these features cost less, then the OEMs will apply them. However, the performance or NVH improvements probably are not worth the increase in cost to most owners.
- A breakthrough in fully electric valvetrains could bring near-100% implementation of variable lift, phasing, and timing control. This would be an enabling technology for drastically improving emissions and fuel economy while maintaining or improving current WOT performance capabilities.

RESULTS SUMMARY

Panelists' forecasts for passenger-car engines in 2009

- Balance-shaft use will increase to 40 percent of four-cylinder engines and 90 degree six-cylinder engines.
- Roller-lifter use will increase to 50 percent of all engines. This is a substantial increase for DOHC and SOHC engines.

- Fewer than 30 percent of engines will have hollow camshafts, lighter valves, powdered-metal cam and gears, variable valve lift, phasing, or timing control. However, panelists expect all these features to increase their penetration rates substantially by 2009.

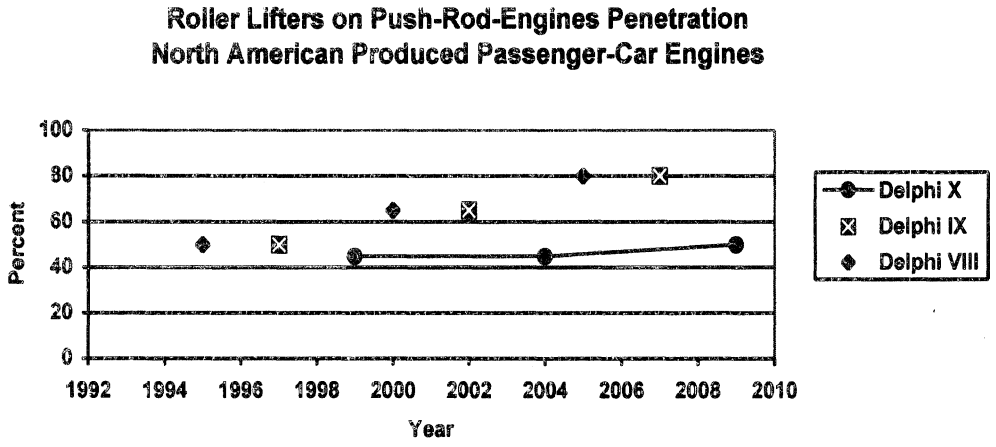
MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table. These differences are relatively small.

ADVANCED ENGINE FEATURES	MANUFACTURER MEAN	SUPPLIER MEAN
BALANCE SHAFT (% OF FOUR-CYLINDER ENGINES) CURRENT EST.	27.1	22.9
BALANCE SHAFT (% OF FOUR-CYLINDER ENGINES) 2004	35.1	31.4
LIGHTER VALVES (20% OR MORE) 2009	18.9	24.1

TREND FROM PREVIOUS DELPHI SURVEYS

Results of the current survey are in general agreement with past surveys with the exception of roller lifters on push-rod engines. The following graph compares the current and past surveys for roller lifters on push-rod engines.



Roller-lifter use on push-rod engines is forecast to be lower in the current survey than in the previous two surveys.

STRATEGIC CONSIDERATIONS

Balance shafts: Balance shafts reduce engine vibration. They are particularly effective on four-cylinder engines, which have a second order unbalance, causing vibration at high engine speeds. The disadvantages include added cost, weight, and complexity. The added weight and increased engine friction are directionally wrong for improved fuel economy. In spite of these disadvantages, panelists forecast increased use of balance shafts to reduce engine vibration and increased customer satisfaction.

Hollow camshaft: This weight-saving feature reduces the amount of cast iron in an engine, and adds a lesser amount of steel. Production of hollow camshafts adds assembly operations, and reduces casting requirements.

Powdered metal cam and gears: Cast iron or forged steel operations will be replaced by metal sintering operations.

Roller lifters: Reduce engine friction but add weight and cost. Roller lifters provide a net fuel-economy improvement of approximately 2 percent, and are one of many incremental improvements to vehicle fuel economy.

Variable lift, timing, and valve phasing control: These cam control devices allow increased engine performance without trading low-speed engine smoothness and emission control. They add cost, weight, and complexity to an engine, but are used increasingly to meet performance, emission, and fuel economy objectives. As one of the panelists noted, a fully electric valvetrain could replace the current camshaft and associated mechanical control devices. One panelist noted in TECH-41 that this will happen on some engines before 2004. This could have a marked negative impact on suppliers of camshafts and cam drives, while providing further opportunity for suppliers of electric actuation devices. With the considerable continuing improvements being made in electrical/electronic components, the camless engine may not be as far away as once thought.

TECH-43 What percentage of current North American-produced vehicle engines will undergo major redesign (greater than 30 percent of the investment cost of a new engine) by 2004 and 2009?

NORTH AMERICAN-PRODUCED ENGINES	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004 (%)	2009 (%)	2004 (%)	2009 (%)
FOUR-CYLINDER ENGINE	25	52.5	20/40	40/80
V6 ENGINE	30	50	20/40	40/75
V-8 ENGINE	22.5	40	15/30	25/80

SELECTED EDITED COMMENTS

- New emissions, CAFE requirements, and the desire to incorporate new technologies (GDI, VVT, etc.) will drive many engine major redesigns.
- With the push for clean air and greenhouse-gas reduction, almost no engine can go ten years without a major redesign just to meet regulations.

RESULTS SUMMARY

Panelists forecast that almost half of North American-produced engines will undergo major redesign (greater than 30 percent of the investment cost of a new engine) by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

There is generally good agreement between the current and past Delphi forecasts.

STRATEGIC CONSIDERATIONS

The forecast for increasing fuel economy standards and tougher emissions standards will drive changes in engine design, as noted in panelist comments. In addition to regulation-driven changes, a number of engine features such as variable valve timing and roller lifters/followers are forecast to increase in use (TECH-42). The forecast for the change from cast iron to aluminum for cylinder heads and blocks (TECH-47) will also drive major engine redesign.

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 be leaders in engine technology and performance, which should continue the high rate of engine redesign.

Another interesting and perplexing issue for the industry is related to the potential for alternative power plants, such as fuel cells or hybrids. As prospects improve for these alternatives, it would appear to place current engine designs at risk. Considering the high cost of engine programs, this may result in an interesting dilemma: the inability to spread the cost of engine tooling over a larger number of years.

TECH-44 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 2004 and 2009?

PASSENGER-CARS FUEL INJECTION	1998*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
DIRECT-CYLINDER INJECTION (GDI)**	0	5	10	1.3/10	5/25
PORT OR MULTIPOINT	100	95	85	90/99	75/95

LIGHT TRUCKS FUEL INJECTION	1998*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
DIRECT-CYLINDER INJECTION (GDI)**	0	3	10	0/10	5/20
PORT OR MULTIPOINT	100	97	90	90/100	80/95

*Source: Ward's Automotive Report, Jan. 25, 1999 and OSAT estimates.
**Gasoline-direct injection.

SELECTED EDITED COMMENTS

- GDI, not worth the trip, i.e., there are cheaper ways to skin the fuel-economy cat. Natural gas looks more promising.
- System cost, fuel quality, and sulfur content (catalyst degradation) will limit the application of GDI in North America.
- The cost and emissions-control challenge will delay the migration toward GDI.
- This depends on the 4/6/eight-cylinder engine mix and legal MPG/competitive requirements/environment.
- Unless major fuel economy or emissions improvements can be realized and required, then the extra cost of GDI will be prohibitive.

RESULTS SUMMARY

Panelists forecast that port or multipoint injection will be used on 85-90 percent of passenger-cars and light trucks through 2009. Direct-cylinder injection is forecast to have a penetration of 10 percent in that time frame.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

The current forecast is in agreement with the last forecast, Delphi IX. Earlier surveys had forecast that throttle-body injection would be used in as many as 25 percent of passenger-car engines and 20 percent of light-truck engines in 2000. Throttle-body injection has been replaced entirely by multipoint injection.

The forecast for direct-cylinder injection is in line with previous surveys, and forecasts an increasing penetration.

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 all passenger-cars and light trucks.

Emissions control, fuel economy, and performance were the driving forces behind these dramatic technology shifts. Carburetors did not provide adequate control for closed -oop emission systems. Throttle-body injection had a lower cost than port fuel injection, and rapidly replaced carburetors. Port fuel injection provides fuel control that is superior to throttle-body injection, and soon replaced throttle-body injection as emission standards became more stringent. Increased engine performance is also obtained by use of multipoint or port fuel injection.

Direct-cylinder injection (really a form of stratified charge combustion) 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 phase-in to Japan, Europe, and then the United States. This system offers inherent fuel economy advantages due to lean mixture combination and potentially reduced throttling losses.

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. A particularly interesting issue is related to the potential for GDI engines in larger vehicles. The specific engine out emissions must be lower for larger vehicles to compensate for greater fuel and air-mass-flow emission. That is, grams per mile equal specific emissions times mass flow. The greater the mass-flow rate, the lower the specific emissions level to meet the standard. Panelists' comments also note that fuel quality may be a problem for direct-cylinder injection.

TECH-45 What percentage of North American-produced spark-ignited engines for passenger-cars will be either supercharged or turbocharged in 2004 and 2009?

SPARK-IGNITED ENGINES	1998* (%)	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004 (%)	2009 (%)	2004 (%)	2009 (%)
SUPERCHARGED	1.2	2	3	1.3/3	2/6.5
TURBOCHARGED	0.1	1	1	0.2/1.3	0.3/4

*Source: Ward's Automotive Reports, Dec. 21, 1998.

SELECTED EDITED COMMENTS

- Cost and CAFE are the issues.
- Future emission standards may be more difficult to achieve with turbocharging (loss of heat energy for catalyst light off).
- Supercharging will remain a niche technology because of cost. Turbocharging will remain irrelevant because of emissions.
- This is highly dependent on fuel price or CAFE standards.

RESULTS SUMMARY

Panelists forecast that 3 percent of passenger-car engines will be supercharged in 2009. In the same time frame, only 1 percent of passenger-car engines are forecast to be turbocharged.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

SPARK-IGNITED ENGINES	MANUFACTURER MEAN	SUPPLIER MEAN
SUPERCHARGED 2009	8.4	3.7
TURBOCHARGED 2009	3.4	1.6

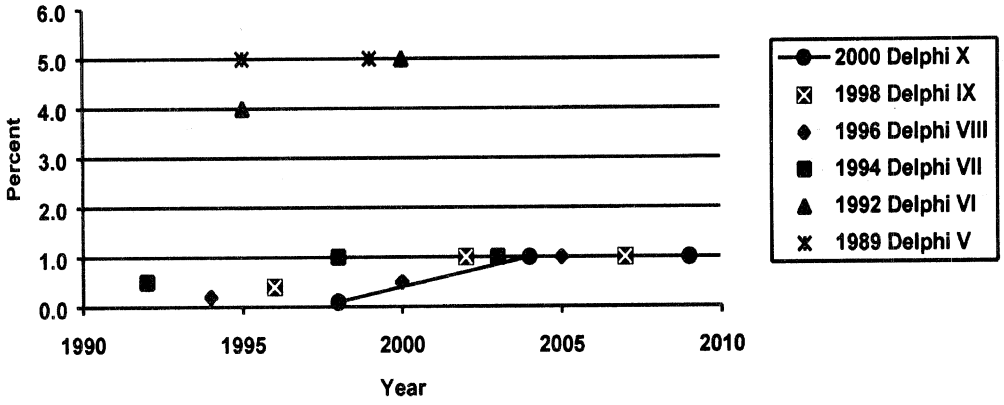
Manufacturers forecast greater use of superchargers and turbochargers than do suppliers. Since vehicle manufacturers generally design their own engines, it is possible that future plans have not been adequately communicated to suppliers.

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.

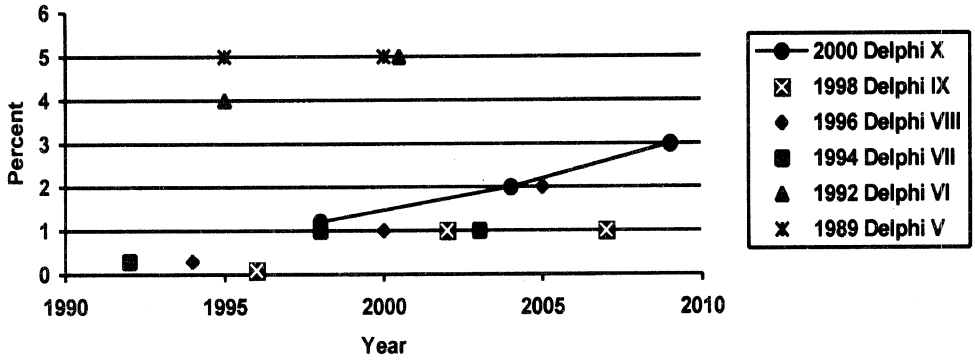
The results of the current survey are compared with those of the previous five surveys in the following graphs.

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 these 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.

Surpercharged Engine Forecasts
North American Passenger Car Production



The forecast of the current survey is similar to that of the previous three surveys. Actual penetration rates are considerably below those forecast in early surveys.

STRATEGIC CONSIDERATIONS

As noted in panelist comments, increasingly more stringent emission standards will likely preclude the use of turbochargers. Cost, durability, and packaging are also concerns for turbochargers.

Superchargers do not take heat from exhaust gas, and therefore do not affect converter light-off time. Cost and packaging are issues, but do not exclude superchargers from upscale vehicles. Superchargers greatly increase low speed engine torque as well as high-speed horsepower. They therefore have an effect similar to increasing engine displacement

dramatically. Superchargers may be used in the future as a fuel-economy enhancement by allowing the use of smaller engines to maintain vehicle acceleration performance.

The increased use of four-valve-per-cylinder engines has somewhat reduced the advantage of a supercharger. Significantly higher horsepower is available from these engines for a given displacement. Low-speed torque is generally not increased, however, with a four-valve-per-cylinder engine without a supercharger.

One general issue with either boost techniques is the trade-off in the cost of turbo or supercharging relative to a new engine program. Also, if you need power fast (design and development time) applying engine boost is faster than developing a new engine.

TECH-46 What percentage of North American-produced passenger-cars and light trucks with spark-ignited engines will incorporate the following ignition-system features in 2004 and 2009? Please provide your estimate for current vehicles.

IGNITION SYSTEM FEATURES	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST.	2004	2009	CURRENT EST.	2004	2009
	(%)	(%)	(%)	(%)	(%)	(%)
PASSENGER-CARS						
COIL-ON-PLUG DESIGNS	10	20	30	6/10	15/20	25/40
CYLINDER PRESSURE CONTROL OF IGNITION	1	5	10	0/1	2/5	5/10
DISTRIBUTORLESS IGNITION SYSTEMS	70	80	90	65/75	70/85	80/95
INDIVIDUAL CYLINDER CONTROL OF IGNITION TIMING	2	10	20	2/5	5/15	10/35
KNOCK/ADAPTIVE CONTROL	50	60	72.5	40/51.3	53.8/70	70/90
LIGHT TRUCKS						
COIL-ON-PLUG DESIGNS	5	12	20	5/5	10/20	15/30
CYLINDER PRESSURE CONTROL OF IGNITION	0	3	7	0/0	1.5/5	5/10
DISTRIBUTORLESS IGNITION SYSTEMS	70	80	90	60/75	70/85	80/95
INDIVIDUAL CYLINDER CONTROL OF IGNITION TIMING	1	10	20	.5/4	5/15	10/30
KNOCK/ADAPTIVE CONTROL	30	45	70	25/40	39/60	50/80
All Vehicles						
MULTIPLE SPARK PLUGS PER CYLINDER	1	5	6	0/4.5	1.5/7.5	2.3/13.8
LONG DURATION SPARK	2	5	12.5	0/10	3/16.3	5/30

OTHER RESPONSES

- Cassette coils (passenger-cars and light trucks). 2009: 15%

SELECTED EDITED COMMENTS

- These technologies will trend strongly towards standard fare in the future—especially the technologies that enable fuel economy, emissions, and performance. Cost is the constraining factor for the lower-end of the product portfolio.
- We expect wide-open-throttle (WOT) individual-cylinder control of ignition timing in both passenger-cars and light trucks.

RESULTS SUMMARY

Panelists forecast that distributorless ignition systems and knock/adaptive control of spark timing will be used on most passenger-car and light-truck engines by 2009. Coil-on-plug designs are forecast for 30 percent of passenger-cars and 20 percent of light trucks by 2009. Limited application of cylinder control of ignition and individual cylinder control of ignition timing are forecast in the same time frame.

MANUFACTURER/SUPPLIER COMPARISON

There are statistically significant differences in responses between manufacturers and suppliers for the items shown in the following table.

IGNITION SYSTEM FEATURES	MANUFACTURER MEAN	SUPPLIER MEAN
PASSENGER-CARS		
COIL-ON-PLUG DESIGNS CURRENT EST.	11.8	8.7
KNOCK/ADAPTIVE CONTROL CURRENT EST.	51.7	42.6
LIGHT TRUCKS		
COIL-ON-PLUG DESIGNS CURRENT EST.	7.7	4.3
DISTRIBUTORLESS IGNITION SYSTEMS CURRENT EST.	70.8	61.7
KNOCK/ADAPTIVE CONTROL CURRENT EST.	39.8	27.1

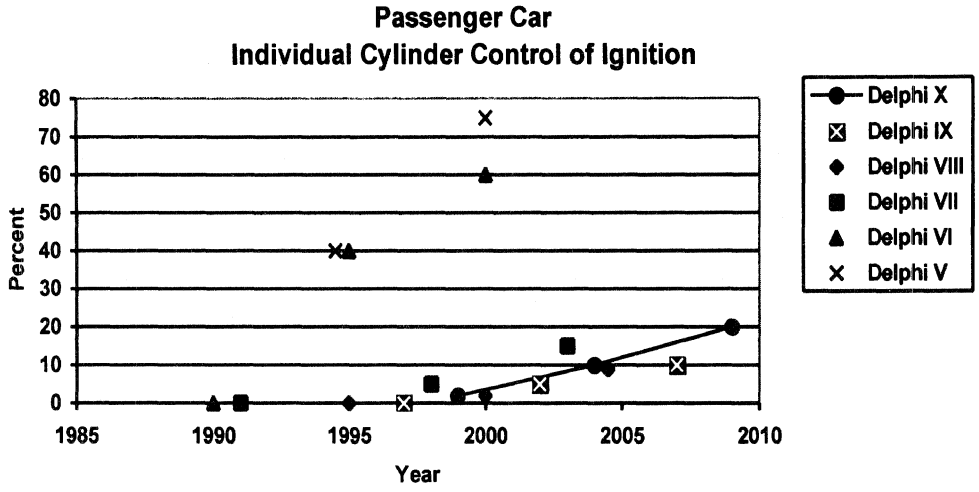
Manufacturers estimate higher current use of coil-on-plug designs, knock/adaptive control, and distributorless ignition than do suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

Passenger-cars: Results of the current survey are in good agreement with past surveys, with the exception of "individual cylinder control of ignition" and multiple spark plugs per cylinder.

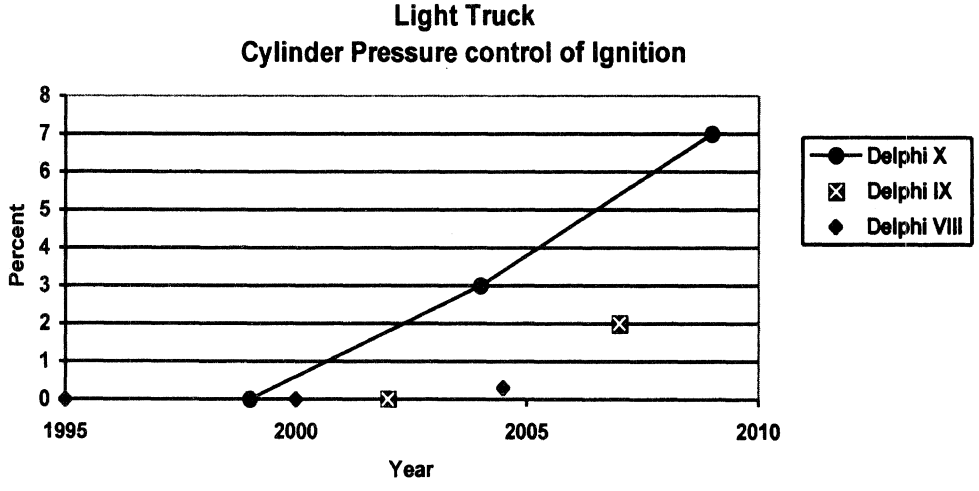
Multiple spark plugs per cylinder were included in the 1996 Delphi VIII survey. An application rate of 0 percent was forecast for 2000 and 2005, compared with 5 percent in 2004 and 6 percent in 2009 in the current survey. Long-duration spark was not included in a previous survey.

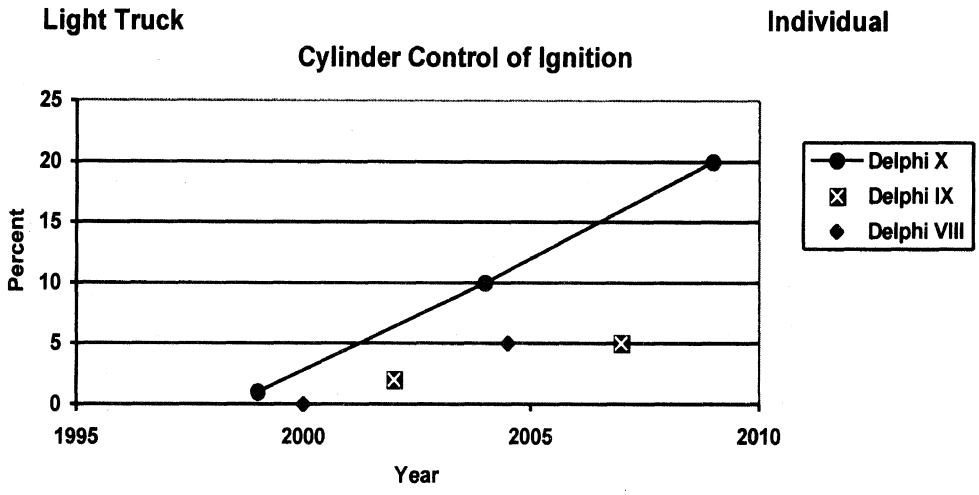
Results for individual cylinder control of ignition are summarized in the following graph.



Early Delphi surveys forecast high application rates for individual cylinder control of ignition. This has not occurred. The results of the current survey are in general agreement with more recent surveys.

Light trucks: This question was asked for light trucks for the first time in the 1996 Delphi VIII forecast. Results of the current and previous two forecasts are in general agreement for coil-on-plug designs, distributorless ignition, and knock adaptive control. The current survey forecasts higher application rates of cylinder pressure control of ignition and individual cylinder control of ignition than the previous two forecasts, as shown in the following two graphs.





STRATEGIC CONSIDERATIONS

Two comments from the 1992 Delphi VI forecast are worthy of note. They are as follows:

- Individual knock control has been badly delayed by excessive patent royalty demands.
- Use of these technologies will increase as patent protection expires.

Panelists in the current survey may be aware that these patent issues will soon be moot, or they may not be aware that patents are an issue.

From the current and past surveys, it appears that when patents are no longer a controlling factor, this technology will be used at an increasing rate.

All of these technologies address more accurate and higher quality control of ignition. They will be used increasingly to reduce exhaust emissions, improve engine smoothness, and increase performance.

The advent of tier-two emission standards during the next decade could unleash a very aggressive approach to engine technologies, including ignition systems. Costs of added levels of emission control could easily exceed $200 per vehicle and, undoubtedly, would include advanced-ignition-system technology.

TECH-47 What percentage of North American-produced passenger-car and light-truck engines in 2004 and 2009 will utilize cast iron or aluminum cylinder heads and blocks?

PASSENGER-CARS MATERIAL	1998*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
BLOCKS					
ALUMINUM	32.0	40	50	37/45	45/70
CAST IRON	68.0	60	50	50/62	30/55
HEADS					
ALUMINUM	88.2	90	95	90/94.3	95/100
CAST IRON	11.8	10	5	7/10	0/5

LIGHT TRUCKS MATERIAL	1998 *	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004	2009	2004	2009
BLOCKS					
ALUMINUM	2.3	10	20	5/15	10/30
CAST IRON	97.7	90	80	85/95	70/90
HEADS					
ALUMINUM	51.2	60	75	60/70	65/85
CAST IRON	48.8	40	25	30/40	15/35

*Source: Ward's Automotive Reports, Dec. 21, 1998 and Jan. 25, 1999; Automotive Industries Engine Insert, Mar. 1998.

SELECTED EDITED COMMENTS

- Aluminum blocks and heads are one of the few, large, mass-reduction "opportunities" still available (where not already implemented) at "reasonable" piece cost. As this is essentially all front-end mass, compounding of benefits is easily applicable. I doubt anyone would consider a major upgrade/new engine program in anything but aluminum.
- Magnesium is coming.
- The increasing number of crossover vehicles and minivans classified as trucks will drive more car-type engines with aluminum content.
- Vary attainable mass reduction by switching to aluminum.

RESULTS SUMMARY

Panelists forecast that aluminum use will increase to account for half of passenger-car engine blocks and 95 percent of cylinder heads by 2009. For light-truck engines, use of aluminum increases to 20 percent of cylinder blocks and 75 percent of cylinder heads by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

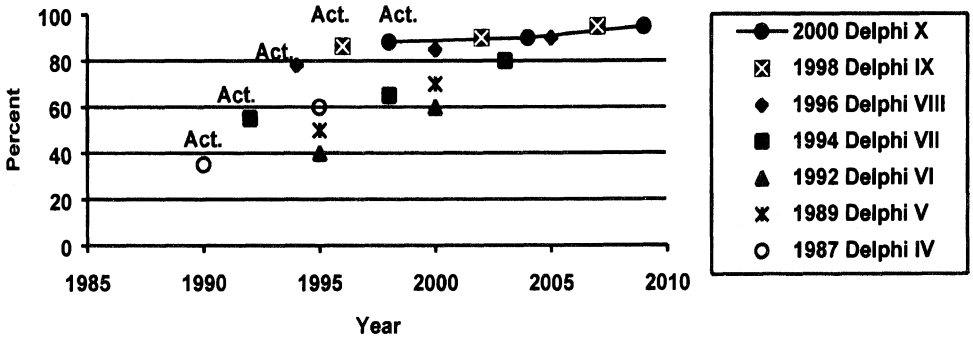
PASSENGER-CARS MATERIAL	MANUFACTURER MEAN	SUPPLIER MEAN
BLOCKS		
ALUMINUM 2009	61.4	51
CAST IRON 2009	40	49
HEADS		
CAST IRON 2004	7.5	9.1

Manufacturers forecast greater use of aluminum in passenger-car engine blocks than do suppliers for 2009.

TREND FROM PREVIOUS DELPHI SURVEYS

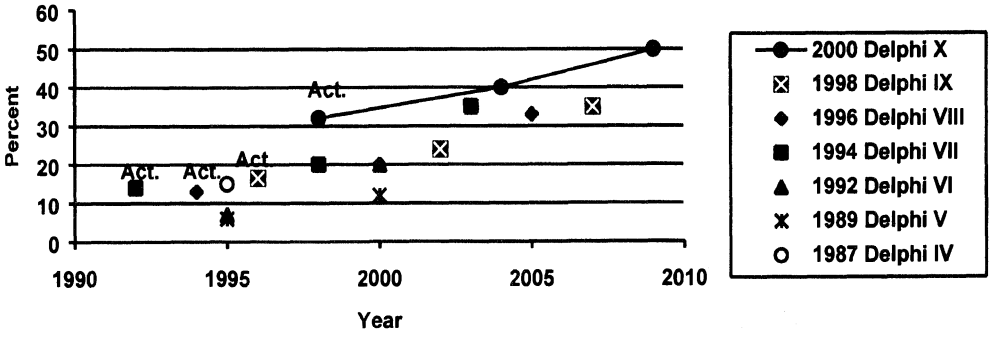
The move to aluminum in passenger-car cylinder heads has proceeded at a faster rate than forecast in earlier Delphi surveys. This trend is shown in the following graph.

Aluminum Cylinder Head Forecast—Passenger Cars



The current estimate for aluminum cylinder heads is higher than forecast in previous surveys for this date.

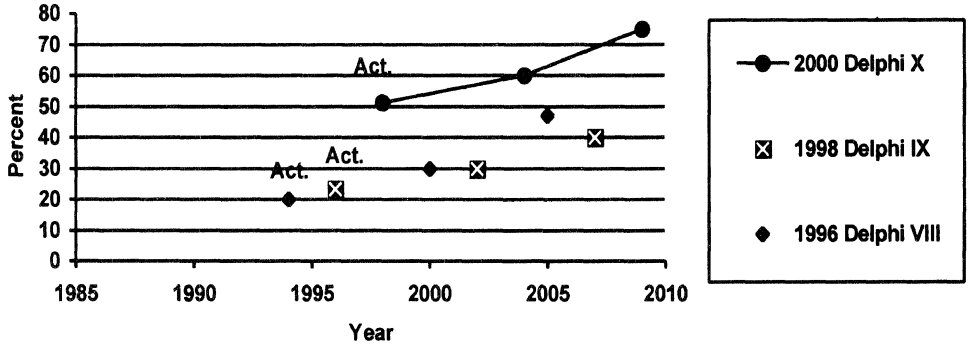
Aluminum Cylinder Block Forecasts—Passenger Cars



The number of aluminum cylinder blocks in passenger-cars in 1998 is greater than forecast in previous Delphi surveys.

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 for cylinder blocks is in good agreement with past surveys. The current penetration of aluminum cylinder heads in light trucks is higher than previously forecast. Forecasts for the future are also higher, as shown in the following graph.

Aluminum Cylinder Head Forecast - Light Trucks



STRATEGIC CONSIDERATIONS

The use of aluminum engine cylinder heads and blocks has accelerated at a rate greater than forecast in previous Delphi surveys.

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.

The comment by one panelist that "magnesium is coming" should be noted. Magnesium has been used in racing engines, but cost and corrosion concerns have limited production applications.

It also should be noted that increasing experience with aluminum may have reduced the cost impact of using this material. Considered at the total systems level, the cost penalty may be far smaller than once believed.

TECH-48 In order to meet federal and California emission standards, what percentage of North American-produced passenger-cars will use lean burn technology with a NOx catalyst by 2009 ?

LEAN BURN TECHNOLOGY WITH NOX CATALYST	MEDIAN RESPONSE	INTERQUARTILE RANGE
	2009 (%)	2009 (%)
TO MEET:		
CALIFORNIA STANDARDS	30	10/65
FEDERAL STANDARDS	20	5/50

SELECTED EDITED COMMENTS

- Lean-burn technology is for federal emission standards; it hurts emissions. No one will use lean NOx just for emissions. California standards probably preclude it.
- Lean burn will have a much more difficult time meeting future emissions standards than current stoichiometric (chemically current fuel/air ratios) engines.
- Sulfur content in fuels must be regulated/controlled to enable this technical solution!!!
- The standards will probably be the same in 2009.

RESULTS SUMMARY

Panelists forecast that lean burn technology with NOx catalyst will be used on 30 percent of passenger-cars designed to meet California emission standards in 2009. Furthermore, they forecast that lean-burn technology with NOx catalyst will be used on 20 percent of passenger-cars designed to meet federal emission standards in 2009

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

There is generally good agreement between the current and past surveys.

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). As noted, it is very difficult to make lean burn engines, presumably with stratified charges (GDI) with very low NOx and HC emissions. This is a particular challenge with larger/heavier vehicles.

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 response to this question suggests significant uncertainty or differences in approach by manufacturers.

TECH-49a What new hardware/technology will be required in order to meet the proposed tier-two emission standards (those that are to be implemented over the next 10 years)?

RESULTS SUMMARY

Catalyst- Improved (10 responses)

- Improved catalyst designs (5 responses)
- Improved catalysts (especially higher temperature tolerance)
- Improved wash coat technology of converters
- Catalyst loading
- More durable, multifunctional catalysts
- Multicell catalyst

Catalyst-Heated (7 responses)

- Electrically-heated catalyst (5 responses)
- Heated converters (2 responses)

Catalyst-Light-off (5 responses)

- Fast light off, low thermal mass catalysts (3 responses)
- Light-off catalysts
- Warm-up catalysts

Catalyst-Lean NOx (9 responses)

- Lean NOx catalyst (4 responses)
- Lean NOx catalyst with sulfur tolerance
- NOx is most challenging
- Lean burn
- Catalytic converters for diesel engines.
- New zero-NOx-emitting catalyst systems

Emission Absorbers (2 responses)

- Absorbent systems for exhaust on startup (cold)
- Systems to store start up emissions and destroy them after the engine is hot

Fuels (13 responses)

- Low-sulfur fuel (<= 30 ppm) (8 responses)
- Alternative fuels
- Sulfur in fuel detection
- Fuel reformulating to support new hardware
- Onboard preprocessing of fuel
- Fuel composition changes

Drive-by-wire (2 responses)

Hybrid (5 responses)

Fuel Cell (3 responses)

Engine controls (9 responses)

- Improved control strategies
- Active control of fuel/air mixture
- Better A/F control
- Engine controls
- Advances in adaptive control
- More ECU capability
- New engine controls - real time burn control
- Much better engine-management control
- More and better electronic controls

Particulate controls (5 responses)

- Urea purged NOx/particulate traps
- Particulate traps (3 responses)
- Particulate controls

Sensors-improved (7 responses)

- Sensors for NOx, HC
- Fast response sensors
- More extensive suite of sensors
- Sensors (2 responses)
- Improved 0_2 sensor technology
- Combustion monitoring (ion sensing)

Valve actuation (6 responses)

- Electronic valve control
- Variable valve timing (4 responses)
- Camless valve actuation

Ignition timing-Individual cylinder control (3 responses)

- Fuel and spark systems timed to the combustion process
- Total control of individual cylinders for spark/ignition engine
- Individual cylinder control of ignition timing

Weight reduction (2 responses)

- Weight reductions or, potentially, load-capacity reductions in SUVs
- Higher use of composite materials for weight reductions

Direct Injection Engines (3 responses)

- Direct injection engines
- Diesel
- Major invention to "save the diesel"

Evaporative Controls (4 responses)

- Evaporative area
- Lower permeation plastic fuel tanks
- Leak proof fuel and evaporator systems
- On-board vapor recovery

Miscellaneous

- A dramatic improvement in energy storage technology
- California systems
- Continued effort to improve battery efficiency
- Improvements to plastics used in the fuel delivery/storage system might be needed to satisfy evaporative standard reductions if alcohol becomes a preferred fuel-oxygenate over MTBE
- Low phosphorous oils
- Powertrain closed loop, including maintenance
- Optimization of existing ideas
- Revisions to products to reduce crevice volume in the combustion cylinder
- Additional electronics (more new "smart" products)
- Sophisticated EGR (fast response, fully modulated)
- The attainment of emissions compliance cannot be divorced from fuel economy and performance. The real question is what changes need to be made to ensure that vehicles meet the consumers ever increasing demands for better performance, room, reliability, and cost of ownership. Assuming that there is no moderation in the trend towards larger and more sophisticated vehicles, I see the following technologies becoming mainstream in the US: CVT transmissions, valve deactivation, supercharging, hybrid vehicles, refinements of existing technology, i.e., lighter/smaller castings, plastic intakes, swirl control valves, machined combustion-chambers, and synthetic oils.
- 42V electrical power systems with integral starter/alternators
- Very fast-starting engines (first or second crank)
- Double layer exhaust pipe
- We don't even have the equipment to measure the level of emissions being discussed. EPA has the assignment to insure availability but nothing yet. Can't comment on balance until actual levels are defined and published.

MANUFACTURER/SUPPLIER COMPARISON

Manufacturer/supplier comparisons are not made for open-ended questions

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

Panelists have identified numerous new hardware and technologies that will be required in order to meet the proposed tier-two emission standards. Considerable development time, effort, and cost must be expended to bring these items to market in the next decade. Development of these items will take resources away from other areas of vehicle development.

One of the panelists made an interesting comment that we are not yet able to accurately measure emissions at these low levels. This certainly creates a challenging situation for persons working in this area. This is not unlike the development of emission systems in the early 1970s. It was difficult then, and it will be difficult now.

TECH-49b What will be the total cost of development, in U.S. dollars, of the new technology and hardware needed to meet the tier-two emissions standards?

TOTAL DEVELOPMENT COST-$BILLION	
MEDIAN RESPONSE	INTERQUARTILE RANGE
$2.5	$1/$7

SELECTED EDITED COMMENTS

- $4 billion (technology) plus $3 billion (fuels to support technology).
- Cost is estimated at $2 million per engine combination with engine defined as the current engine family EPA definition. That is, if two displacements, the $2M is for both. I estimate $500,000 for a different transmission.
- Engine torque sensor will be introduced.
- For all automotive manufacturers, for all vehicles: at least $1 billion
- The cost includes both the fuel (desulphurization) and the vehicle system. On the vehicle, more effective affordable catalysts, engine controls, improved sensors for emission detection, exhaust sensors for engine monitoring, better exhaust sealing to prevent exhaust contamination, input stream nitrogen filters, reduced engine displacement with turbo charge or other, perfect Miller cycle, or other improvements could require hundreds of millions of dollars to develop and implement by the automotive industry. The goal of tier-two NOx levels at a reasonable, $1000/vehicle, or else reduce the typical engine displacement by 50% and use off the shelf technology.
- The estimated costs are linked to the negotiation process so development costs can only be speculated. I project that development costs will average about $20 per vehicle for exhaust and $3 per vehicle for evaporative/refueling emissions, or a total of $23 per vehicle for the tier-two rule.
- Two million for each supplier who works on it.

RESULTS SUMMARY

Panelists forecast that total cost of development of the new technology and hardware needed to meet the tier-two emissions standards will be $2.5 billion.

MANUFACTURER/SUPPLIER COMPARISON

Manufacturer/supplier comparisons are not made for open-ended questions

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

Development of new technology and hardware needed to meet tier-two emissions standards will place a financial burden on both manufacturers and suppliers. Suppliers must determine how to absorb these costs, as they likely will not be able to pass them on directly to vehicle manufacturers. Also, the energy industry will be impacted because of the need to reduce fuel sulfur contamination.

TECH-49c What percentage of total vehicle cost will be attributable to meeting the tier-two emission standards in 2004 and 2009?

TIER-TWO EMISSION STANDARDS	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004	2009	2004	2009
% OF VEHICLE COST	5	7	2/10	3/10

SELECTED EDITED COMMENTS

- Assume a nominal $20,000 car, which costs the OEM $12,000 to make, (not counting profit, advertising, and warranty, you did say cost) 4% is 480 dollars, which would buy two or three of the major technologies listed in 63a.
- Cost of hardware. Development and calibration costs are harder to allocate because each manufacturer uses a different method.
- Differential cost from today's emissions cost as baseline.
- More expensive engine and converter technologies.
- Part of incurred cost will be in maintenance and government inspections and administration.
- The percentage probably ranges between 2% and 10% depending upon overall vehicle cost.
- There has to be a limit on cost somewhere. As more and more of the North American consumer population is pushed out of the new-car market by rising costs, I think we will find it.

RESULTS SUMMARY

Panelists forecast that 7 percent of total vehicle cost will be attributable to meeting tier-two emission standards in 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no significant differences in responses for manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

Assuming the cost of an average vehicle at $20,000, the cost of tier-two emission standards is forecast at $1,400 per vehicle in 2009. As noted in the comment of one panelist, this increase will likely price some potential customers out of the new-vehicle market. This could have dramatic ramifications on the entire industry. It is likely that the current drive to contain vehicle costs will become more intense in the next decade.

TECH-50 What will be the most challenging aspect of attaining the proposed tier-two emission standards?

RESULTS SUMMARY

Cost: (11 responses)

- Affordable NOx reducing systems that will work w/ North American large displacement engines.
- Cost.
- Getting fuel cell costs down.
- Keep vehicle cost low. Save noble metal.
- Keeping the cost out.
- Keeping vehicle costs within reach of the average consumer.
- Maintaining functionality of trucks, and doing it on an affordable basis.
- Meeting the emission standards while also achieving the needed fuel economy and controlling cost.
- Meeting the requirements while maintaining or reducing component/system costs.
- Obtaining/justifying the funds to support this effort.
- Passing on the cost impact of development and new hardware plus packaging it.
- Taking cost out for commercial viability.

Durability: (6 responses)

- 100K durability.
- System deterioration: High deterioration factor = high initial efficiency catalyst/slightest change.
- Durability of engine components.
- Durability of systems.
- Longer term durability and performance of systems in the field.
- To meet it over life cycle of the car.

Meeting the Requirements: (5 responses)

- Elimination of all pollutant gasses.
- Equally NOx and evaporative emission.
- Light trucks meeting car emissions standards.
- Meeting the requirements while also meeting expected CAFE and greenhouse standards.
- Reducing emissions on large displacement engines.

Catalyst Light-Off Time: (3 responses)

- Attaining catalyst activity quickly enough to eliminate emissions during the first few seconds of the test cycle.
- HC light-off with some engines.
- Start-up and warm-up emissions.

Diesel Engine Compliance: (2 responses)

- Diesels.
- Continuing to offer the fuel efficient diesel, especially in California.

Fuels: (2 responses)

- Changes in fuel will be required to meet the new standards.
- Timing the introduction of new fuel standards, e.g., percentage of sulfur, to be available in time to support emerging technologies.

Performance: (3 responses)

- Achieving the emission standard without sacrificing performance while controlling costs to a reasonable economic level, acceptable to the customer.
- Meeting consumer demands of fuel economy, performance, and cost while meeting legislative constraints.
- Tier-two will require drastic emission reductions without compromising vehicle performance or load-carrying capacity as was experienced in passenger-cars from 1976 to 1990. This is probably the greatest challenge.

Other:

- Development test consistency.
- NOx OBD (On-board diagnostic) control.
- EMS stability.
- Managing product liability.
- None. I don't think the U.S. carmakers are going to accept them, and are going to fight for their repeal/revision. The people who care about emissions for the most part don't buy Ford or Chevy anyway, and the people who like big SUVs want to able to get them in the future. Between now and when the engineering takes place for 2009 vehicles many things about that legislation could change.
- Reliably measuring the extremely low exhaust levels to demonstrate compliance.
- Timing.

Panelists forecast that the most challenging aspects of attaining the proposed tier-two emission standards will be cost and durability. Numerous other aspects were also noted as presenting challenges.

MANUFACTURER/SUPPLIER COMPARISON

Manufacturer/supplier comparisons were not made for open-ended questions.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

Manufacturers face a formidable challenge in development of systems to meet the proposed tier-two emission standards. New hardware will likely increase vehicle weight and cost. This

comes at a time when manufacturers are trying to reduce weight for improved fuel economy and reduce cost to maintain or increase competitive positions. Vehicle affordability is already an issue, and cost increases for additional emissions systems may exacerbate this situation. The manufacturer that develops the lowest cost systems for meeting tier-two emission standards will have a competitive advantage.

System durability is noted by several panelists as a challenge in meeting tier-two emission standards. Improved fuels may also be required in order to make compliance with these more stringent standards feasible, to avoid catalyst contamination from impurities in the fuel.

It will be particularly important to reduce the engine oil emissions to lower the burden placed on the after-treatment system.

Finally, technical breakthroughs may be required in the development of NOx catalysts.

TECH-51 What percentage of North American-produced passenger-car spark-ignited engines will incorporate the following plastic components in 2004 and 2009? Please provide your estimate for current vehicles.

PLASTIC COMPONENTS	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST.	2004	2009	CURRENT EST.	2004	2009
	(%)	(%)	(%)	(%)	(%)	(%)
FUEL RAILS	10	20	40	10/13.8	20/25	30/35
INTAKE MANIFOLD	20	30	57	15.8/20	30/40	50/60
OIL PAN	2	10	15	2/4.5	5/10	10/20
PISTON SKIRTS	0	1	2	0/0	0/1	0/4
THROTTLE-BODY	8	15	30	5/10	10/20	20/40
VALVE COVERS	15	25	50	10/20	25/30	35/51.3

OTHER RESPONSES

- Laminates - Current estimate: 0%; 2004: 5%; 2009: 10% (Either steel/plastic/steel or aluminum/plastic/aluminum)
- Transmission Components - Current: 2%; 2004: 15%; 2009: 25%
- Water pump assembly - Current estimate: 0%; 2004: 5%; 2009: 10%

SELECTED EDITED COMMENTS

- Plastic valve covers are too noisy, magnesium is better.
- Plastics are getting pretty darn good and even Detroit is starting to accept them for engine applications.
- CARB LEV-II and US EPA tier-two evaporative emissions rules are unnecessarily strict and will limit the use of plastic for fuel rails.
- I still think magnesium makes a better valve cover, but plastic water pumps and thermostat housings make good sense.
- If thermal issues could be solved, transmission cases and valve bodies are excellent candidates for replacement by plastic components.
- New evaporative emission rules that phase in starting in 2004 MY may add a new challenge to plastic fuel rails, intake manifolds, and oil pans. More expensive multilayer constructions or high-tech resins may be needed to limit fuel permeation through component walls. That may increase the appeal of nonporous, lightweight metals.

RESULTS SUMMARY

Panelists forecast that in passenger-cars at least half of fuel rails, intake manifolds, and valve covers will be made of plastic by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There is a statistically significant difference in responses between manufacturers and suppliers for valve covers in 2009 as shown below.

PLASTIC COMPONENTS	MANUFACTURER MEAN	SUPPLIER MEAN	MANUFACTURER MEDIAN	SUPPLIER MEDIAN
VALVE COVERS 2009	49.4	41.0	50	45

Manufacturers forecast a somewhat higher use of plastics in valve covers than do suppliers in 2009.

TREND FROM PREVIOUS DELPHI SURVEYS

There is good agreement between the current and past forecasts.

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.

The issue of recycling may negatively impact the use of plastics in the future. Also, as noted in the comments, the issue of more strict, future, evaporative emission standards may negatively affect plastic use in fuel rails. One of the "other" comments suggested future use of plastic and metal laminates. This may offer the advantages of both plastics and metals for some applications.

The move to plastics will negatively impact some suppliers as it helps others. In some cases, for example, inlet manifolds, we are already moving to second-generation plastics technology.

TECH-52 Please estimate the mix of transmissions for passenger-cars and light trucks manufactured in North America in 2004 and 2009. Total manual plus total automatic should equal 100 percent.

PASSENGER-CARS		MEDIAN RESPONSE		INTERQUARTILE RANGE	
TRANSMISSION	1998*	2004	2009	2004	2009
MANUAL					
FIVE-SPEED	10.4	10	9	8/10	6/10
SIX-SPEED	0.3	1	1	0.3/1	0.5/2
TOTAL MANUAL	10.7	10.3	10	10/11	7.5/12
AUTOMATIC					
THREE-SPEED	6.4	5	2	2/5	0/4
FOUR-SPEED	82.0	80	73.5	76.5/82.8	62.3/80.4
FIVE-SPEED	0.0	2	5	0.8/5	2/10
CONTINUOUSLY VARIABLE (CVT)	0.9	2.5	7.8	1.1/5	4/20
TOTAL AUTOMATIC	89.3	89.8	90	89/90	88.8/92.3

LIGHT TRUCKS		MEDIAN RESPONSE		INTERQUARTILE RANGE	
TRANSMISSION	1998*	2004	2009	2004	2009
MANUAL					
FIVE-SPEED	12.9	12	10.5	10/13	10/13
TOTAL MANUAL	12.9	12	10	10/13	10/13
AUTOMATIC					
THREE-SPEED	2.2	1	0	0/2	0/1
FOUR-SPEED	84.0	84.9	84	80/86	75/86.8
FIVE-SPEED	0.0	2	5	0/7	1.8/15.3
TOTAL AUTOMATIC	86.2	88	90	86.8/90	86.2/90

* Source: Ward's Automotive Reports, Dec. 28, 1998 and Feb. 1, 1999.

OTHER RESPONSES

- "Tip-tronic" type transmissions. Current: 2%; 2004: 4%; 2009: 10%

SELECTED EDITED COMMENTS

- CVTs should be an option for light trucks, at least by 2009. Crossover vehicles will also be likely to use them.
- Expect a major increase in CVTR usage as torque capability increases and the technology proves itself viable.
- The six-speed auto is coming.

RESULTS SUMMARY

Panelists forecast that four-speed automatic transmissions will be used in most passenger-cars (73.5 percent) and light trucks (82 percent) in 2009. Limited, but increasing, applications of five-speed automatic transmissions and continuously variable transmissions in passenger-cars are forecast in the same timeframe. Still, the expected growth in CVTs is quite substantial.

MANUFACTURER/SUPPLIER COMPARISON

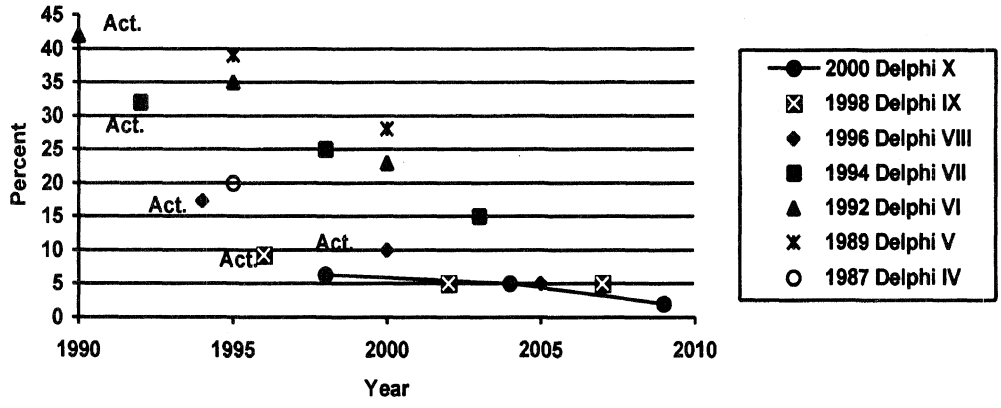
There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

Light trucks were not included in forecasts prior to 1996 Delphi VIII. There is generally good agreement between the current and past forecasts for light trucks, with the exception that the Delphi IX survey forecast lower four-speed automatic (73 to 77 percent) and higher five-speed manual transmission (15 to 17 percent) compared with the current survey.

For passenger-cars, three-speed automatic transmissions have been replaced by four-speed transmissions at a rate higher than forecast in earlier surveys. This trend is shown in the following graph.

Three-Speed Automatic Transmission Forecast
Passenger Car



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. Vehicle acceleration performance is also enhanced with a greater number of forward speeds. 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. The increased cost of the greater number of forward speeds will be partially recovered by the consumer through improved fuel economy. Also, there is an increasing perception that three-speeds are obsolete technology, and, therefore, not desired by consumers.

Some application of continuously variable transmissions (CVT) is forecast by 2009 for passenger-cars. The forecast for increasing fuel-economy requirements is the driving force behind this move. It appears that CVTs can match the mechanical efficiency of manual transmissions. Some impressive developments in CVT technology appear to be on the horizon that could have a significant impact on their use.

Automatic transmissions continue to dominate, and little change in the manual-and-automatic-transmission mix is forecast.

TECH-53 Sequential-shift automatic transmissions are already available, and other transmission features may be on the horizon. Please forecast the percentage of passenger-cars and light trucks produced in North America that will incorporate each of the following transmission features by 2004 and 2009.

TRANSMISSION FEATURE	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004 (%)	2009 (%)	2004 (%)	2009 (%)
PASSENGER-CARS				
AUTOMATIC TRANSMISSION W/O TORQUE CONVERTER	2	10	1/10	2/20
MANUAL TRANSMISSION WITHOUT MANUAL CLUTCH	2	5	1/5	2/15
SEQUENTIAL-SHIFT AUTOMATIC TRANSMISSIONS	5	10	2/10	5/25
LIGHT TRUCKS				
FOUR-WHEEL DRIVE INTEGRATED INTO TRANSMISSION - NO SEPARATE TRANSFER CASE.	3.5	10	0.8/10	5/20

SELECTED EDITED COMMENTS

- Another category would be automatic transmission with limited function torque converter, which has the potential to be 20% by 2009.
- Electronic shift control or "shift by wire" will be an enabler for styling features and new transmission features.
- The first three transmission options have been available for some time, they just don't offer any great advantage, either from a performance or marketing standpoint. The growth of small SUVs, i.e., cheap four-wheel drives, will probably mean integral transmissions, mounted to east-west engines, i.e., normally front-wheel drive.

RESULTS SUMMARY

Panelists forecast limited application (10 percent or less) in passenger-cars of sequential-shift automatic transmissions, automatic transmissions without torque converters, and manual transmissions without a clutch by 2009.

Four-wheel drive integrated into the transmission, with no separate transfer case is forecast for 10 percent of light trucks by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was first asked in 1998 Delphi IX. Light trucks were not covered in a previous forecast.

The current survey forecasts higher use of each of the three passenger-car transmission options than previous forecasts. This is shown in the following table.

TRANSMISSION FEATURE	MEDIAN RESPONSE	
	2007 DELPHI IX (%)	2009 DELPHI X (%)
PASSENGER-CARS		
AUTOMATIC TRANSMISSION W/O TORQUE CONVERTER	5	10
MANUAL TRANSMISSION WITHOUT MANUAL CLUTCH	2	5
SEQUENTIAL-SHIFT AUTOMATIC TRANSMISSIONS	5	10

STRATEGIC CONSIDERATIONS

Sequential-shift automatic transmissions provide the driving convenience of an automatic transmission, with some of the driver feel of a manual transmission. This feature is likely to be used on sporty image vehicles only.

Automatic-shifting manual transmissions may be used to provide the convenience of an automatic transmission and the fuel economy of a manual transmission. This transmission has an electronically operated clutch, which eliminates the manual clutch. 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. (See Tech-1 and Tech-2)

The comments in this questionnaire worth noting are suggestive of some interesting innovations in the transmission horizon.

TECH-54 What percentage of North American-produced vehicles will use the following drivetrain configurations in 2004 and 2009?

DRIVETRAIN CONFIGURATION	1998* (%)	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004 (%)	2009 (%)	2004 (%)	2009 (%)
PASSENGER-CAR					
FRONT ENGINE, FRONT DRIVE	91.0	91	91	90/92	85/94
FRONT ENGINE, REAR DRIVE	7.6	6.6	5	5/8	3/8
FRONT ENGINE, FOUR-WHEEL OR ALL-WHEEL DRIVE	1.4	2	3	1.6/3	2/5
MINIVAN					
FRONT ENGINE, FRONT DRIVE	81.4	82	81.2	80/85	78.8/85
FRONT ENGINE, REAR DRIVE	7.9	5	4	5/7	1/5
FRONT ENGINE, FOUR-WHEEL OR ALL-WHEEL DRIVE	10.8	12	15	10.8/15	10/20
PICKUP TRUCK					
FOUR-WHEEL OR ALL-WHEEL DRIVE	37.8	40	42	39/42.5	40/47.5
SUVS					
FOUR-WHEEL OR ALL-WHEEL DRIVE	74.5	77	80	75/80	75/85

*Source: Ward's Automotive Reports, Dec. 28, 1998, Jan. 18, 1999, Feb. 1, 1999, and OSAT estimates.

SELECTED EDITED COMMENTS

- More crossover vehicles will result in more all-wheel-drive configurations on the road.
- The four-wheel drive has big safety appeal by implying that you won't get stuck.

RESULTS SUMMARY

Panelists forecast that drivetrain configurations for passenger-cars will remain nearly constant through 2009, with front engine, front drive accounting for more than 90 percent of vehicles.

Front engine, front drive is also forecast to remain the dominant configuration for minivans (81.2 percent) in 2009.

Most SUVs are forecast to remain four-wheel or all-wheel drive (80 percent)

The use of four-wheel or all-wheel drive is forecast to increase a bit for all passenger-cars and light trucks.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

DRIVETRAIN CONFIGURATION	MANUFACTURER MEAN	SUPPLIER MEAN
PASSENGER-CAR FRONT ENGINE, REAR DRIVE 2009	7.6	4.9

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked for light trucks in a previous Delphi forecast.

There is good agreement between the current and past survey forecasts for passenger-cars, with the exception that earlier surveys forecast 3 to 5 percent four-wheel or all-wheel drive for 1995 and 2000. This has not materialized, as evidenced by the 1998 estimate of 1.4 percent.

STRATEGIC CONSIDERATIONS

Front engine, front drive is forecast to remain the dominant drivetrain configuration in passenger-cars through 2009. 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 many high-performance passenger-cars. 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.

Luxury vehicles such as Cadillac and Lincoln with front-wheel drive have been criticized for degradation in performance and handling. Vehicle manufacturers must be cautious in response to this criticism, considering the age demographics of Cadillac and Lincoln buyers. Many older drivers will gladly accept the trade-off of some degradation in performance and handling for the greatly improved traction characteristics of front-wheel drive. This is particularly true of those living in northern climates, or those who travel to the mountains in the winter. In fact, it is likely that the typical driver of these vehicles cannot differentiate the handling characteristic differences between front and rear-wheel drive. It is probable that many Cadillac or Lincoln owners would not buy this vehicle if it did not have front-wheel drive and would buy another luxury vehicle that did have front-wheel drive.

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 overseas by foreign manufacturers. This may be a chicken and egg phenomenon. If it were available, it would possibly sell. Half-hearted efforts in the past by domestic manufacturers to market all-wheel-drive vehicles have not been successful. In general, the vehicles brought to market were not refined or fully developed. Panelists forecast an increase in four-wheel or all-wheel drive in both passenger-cars and light trucks. This would also include crossover vehicles that have characteristics of both passenger-cars and sport utility vehicles.

Minivans are predominately front drive, and are forecast to remain so for the next decade. Rear-wheel drive is used in some minivans that are used predominately as delivery vehicles, hauling large loads and carrying most of the weight on the rear wheels. Significant growth is forecast in four-wheel drives for minivans. This could include crossover-minivan-SUV hybrids off of a minivan platform.

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VII. ELECTRICAL AND ELECTRONICS

TECH-55 For a typical North American-produced midsized passenger car, what percentage of total vehicle cost is attributable to electrical and electronic systems currently, and will be in 2004 and 2009? Please include motors, wires, electronics, and all other electrical components in your estimate. What percentage of total vehicle cost will be attributed only to electronic components? Please provide your estimate for current vehicles.

VEHICLE ELECTRICAL/ELECTRONIC COST AS PERCENTAGE OF TOTAL VEHICLE COST	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST. (%)	2004 (%)	2009 (%)	CURRENT EST. (%)	2004 (%)	2009 (%)
A. TOTAL COMBINED ELECTRICAL AND ELECTRONIC COST	20	25	31.5	15/25	22/32.3	24.3/40
B. TOTAL ELECTRONIC COST	10	15	20	8/15	11/20	15/25
ELECTRONIC COMPONENT CLASSES						
ACTUATORS ("SMART" ACTUATORS - DOES NOT INCLUDE TRADITIONAL ELECTRIC-POWERED DEVICES LIKE POWER SEATS OR BLOWERS)	2	4	5	1/5.5	2/12.8	3/13.5
SEMICONDUCTORS/MICROPROCESSORS (ACTIVE DEVICES)	4	6	8.5	1.8/6.3	3/8.5	3/15.5
SENSORS (E.G., WHEEL SPEED, THROTTLE POSITION)	3	4	6	2/5	3/5.8	4.8/10.5

SELECTED EDITED COMMENTS

- Electric costs go down but the number of applications go up, equaling a relatively slight change in total cost for electronics.
- I don't know the allocation specifics, but these electrical technologies will be significantly increased to enable more electrical system comfort and convenience features and content, and to meet safety and legislative requirements. An especially big player in this is in-vehicle communications information, and internet-pc-interconnected-car concept (aka infotronics) with plug-and-play capability. This is part of a very, very significant technology revolution and should be a predominant finding/outcome from this Delphi X study.
- Semiconductor costs will hold constant. As capability increases, unit cost drops. Smart actuators should be called better if cheaper, which smart actuators frequently are not.

RESULTS SUMMARY

The total electrical and electronic cost incorporated in a vehicle is forecast to increase by more than 50 percent in the next decade to nearly one-third the total cost of the vehicle.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

VEHICLE ELECTRICAL/ELECTRONIC COST AS PERCENTAGE OF TOTAL VEHICLE COST	MANUFACTURER MEAN	SUPPLIER MEAN
TOTAL ELECTRONIC COST CURRENT	15.6	9.1
TOTAL ELECTRONIC COST 2004	20.2	13.8
SEMICONDUCTORS/MICROPROCESSORS (ACTIVE DEVICES) CURRENT	15	4
SEMICONDUCTORS/MICROPROCESSORS (ACTIVE DEVICES) 2004	15.7	6.5

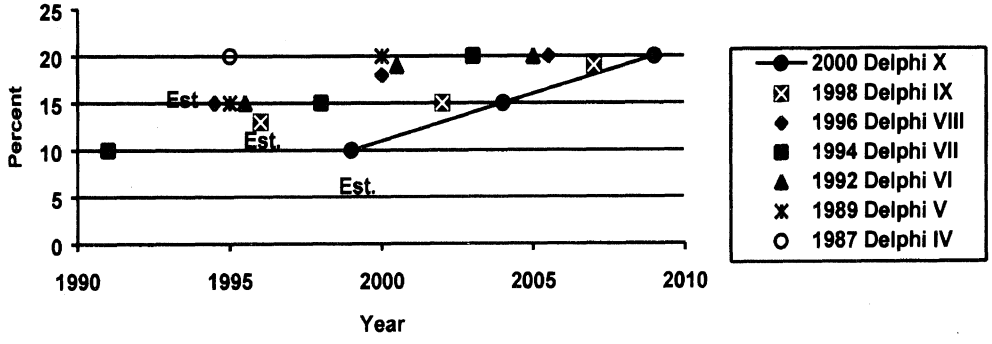
Manufacturers estimate a higher cost for electronics and semiconductors currently and forecast a higher cost in 2004 than suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was asked in this format for the first time in the 1998 Delphi IX forecast. The results from the two forecasts are very similar, with the exception that total combined electrical and electronic cost was forecast at 24 percent for 2007 in Delphi IX compared with 31.5 percent in Delphi X.

In earlier Delphi forecasts, this question was asked only for electronic content. The results of the current survey for electronic content are compared with those of previous surveys in the following graph.

Electronics as Percentage of Total Vehicle Costs Forecast
North American Passenger-Car Production



In each of the past surveys, the forecast has been that the electronics content would be approximately 20 percent in 10 years. In fact, the estimated current cost of electronics has decreased in each forecast.

STRATEGIC CONSIDERATIONS

Increasing government regulation and customer demand for new features will continue to drive up the electronics content in a vehicle. As a result, panelists forecast an increase in the total electronic cost in a vehicle. Some panelists note in their comments, however, that the increase in content will be offset by decreases in cost of individual components. This phenomenon is very evident in the computer industry. The speed and memory of personal computers has grown exponentially in the past decade, at the same time that the cost of a computer has decreased dramatically. Looking at the estimates of the current cost of electronics from past Delphi forecasts indicates that the cost of electronics in a vehicle has actually decreased in recent years, even as content has been added.

Most new features that are being considered for the future will heavily depend on electronics as an enabling technology. Some examples of emerging technologies are night vision, navigation, blind-spot object detection, new airbag systems, antilock braking systems, and advanced engine and transmission controls. See TECH-59 for additional examples.

The advancements in vehicle electronics offer limitless new design concepts to engineers. This will be an exciting area to watch in the next decade.

TECH-56 What percentage of North American-produced passenger cars will utilize at least one multiplexed (MPX) power subsystem by 2004 and 2009? Please provide your estimate for current vehicles.

PASSENGER CAR	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST. (%)	2004 (%)	2009 (%)	CURRENT EST. (%)	2004 (%)	2009 (%)
MULTIPLEXED POWER SUBSYSTEM UTILIZATION	0.5	1.5	3.8	0.2/1.5	0.8/4	2/7.3

SELECTED EDITED COMMENTS

- Enabler for weight and reliability savings; cost too if E/E content is high enough. Industry (DAE) must set standards to enable full cost-savings potential.

RESULTS SUMMARY

Panelists forecast a modest increase in the use of multiplexed power subsystems in the next decade.

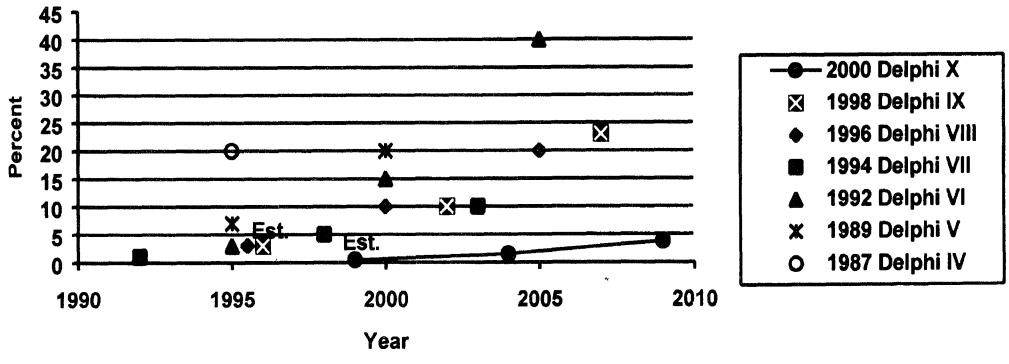
MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

Results of the current survey are compared with those of past surveys in the following graph.

Multiplexed Power Subsystem Forecasts North American Passenger-Car Production



The application of multiplexed power systems has not been as widespread as forecast in previous Delphi surveys. Panelists in the current survey are also much more cautious regarding future application of this technology than were previous panelists.

STRATEGIC CONSIDERATIONS

The application of 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. Panelists are currently pessimistic regarding widespread future application of multiplexed power subsystems in vehicles.

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. It appears that work is intensifying in mulitplexing, and cost breakthroughs could occur at any time.

TECH-57 Microelectromechanical systems (MEMS) integrate and miniaturize electronics and mechanical technologies. Airbag triggering systems are among its current automotive applications. Please identify the three most important automotive applications that you think will be developed in the next five years.

RESULTS SUMMARY

ABS (2 responses)

Airbag

- Air bag triggering (2 responses)

Tire pressure (3 responses)

Dynamic ride/handling control

- Sensing wheel motions for smart suspension systems
- Vehicle dynamic sensing for smart handling systems (5 responses)
- Multiaxial quick response guidance sensor like mini-gyros for vehicle handling and stability
- Suspension (ride) control (7 responses)

HVAC control

- Air-quality monitoring for interior cab air recirculation
- Climate control
- HVAC system door actuators (2 responses)

Proximity of other vehicles

- Proximity-of-other-vehicle indicator, which controls braking
- All warning systems, i.e., backup detection systems
- Adaptive cruise control
- Collision avoidance (5 responses)
- Vehicle crash avoidance such as roll-rate warning and control, blind spot ID

Drive by wire (5 responses)

Load sensing (4 responses)

Miscellaneous

- Acoustic sensors
- Adaptive-learning engine systems
- Anti skid brake technology
- Anti-theft systems (3 responses)
- Any selection would be highly speculative, given the disappointingly slow progress to date.
- Audio speaker systems capable of planar packaging
- Brake by wire (electromechanical and all electric).
- Catalytic converter light-off

- Combustion monitoring
- Combustion spark
- Drowsy-driver detection
- Electric motors - window and door locks
- Electric, multi-wheel variable steering
- Electronic-controlled, variable, independent, valve timing
- Electronics/telematics devices (actuators) (2 responses)
- Emission controls with exhaust gas analysis
- Engine air and fuel control
- Engine controls
- Engine systems such as valve timing, lift, and phasing
- Ergonomics, in-cabin controls
- Flow sensors
- Fluid-flow control
- Fuel cells
- Gyros for rollover
- Ignition control clocks
- Increased efficiency on engine and drivetrain electronics
- Innovative sensor technologies
- Instrument clusters (to achieve more functions in the current package)
- Internet connections and voice detection
- Knock sensors
- Low-cost electronics everywhere
- Low-cost navigation system (2 responses)
- MEMS are not widely understood yet in the auto industry but I will guess that applications will be developed as microrelays in the electrical system (e.g., move external electro mechanical relays into engine controller), in vehicle optronics (e.g., rear-view cameras), and in instrument panel controls (e.g., on-board computer with MEMS-based joystick).
- Micromotors
- Microrelays in electronics package
- Multiplexed components
- Navigation sensor corrections
- New engine controls
- Occupant protection systems
- Oil quality monitoring. Supertight emissions regulations will require rigid lubricant changes to meet over long periods of time, but, the cost of disposing of used oil will also rise, so the net requirement will be that oil can and must only be changed when its performance starts to deteriorate.
- Power windows, locks, doors, seats, etc.
- Power seat actuator
- Pressure sensors

- Pressure sensors are MEMS now, ~75 of volume. They will continue to grow to higher pressures and tire pressure. Gyros for vehicle attitude and navigation. IR as temperature sensor or night vision.
- Regenerative braking systems
- Seats
- Sensors for emission analysis and actuators for engine emission control
- Sensors (physical proximity for occupant protection and relative position; power switching); fluid flow regulation (fuel systems)
- Smart locks
- Smart-safety algorithms
- Telematics
- Traction control
- Transmission control
- Variable antennae
- Visual systems based on the digital micromirror technology. This could include multifunction displays for instrumentation, navigation, and other telematics features, as well as refinements to night vision systems, etc.
- Voice activated systems

MANUFACTURER/SUPPLIER COMPARISON

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

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

Panelists have identified many potential uses for microelectromechanical systems (MEMS). These devices were first used in vehicles for airbag-deployment sensors and engine-mass airflow sensors. As evidenced by the list of responses, the application is in its infancy, and could expand dramatically in the next decade. Applications are only limited by the imagination of designers and our ability to manufacture components and systems cost effectively.

TECH-58 Telematics is a combination of information technology and telecommunications. Please provide your estimate of what percentage of vehicles in 2009 will incorporate telematics features. For vehicles that incorporate telematics, what percent of their total cost will be attributable to these features? Please provide separate estimates for nonluxury (<$25,000.00) and luxury (≥$25,000.00) passenger cars.

TELEMATICS CONTENT AS A PERCENTAGE OF VEHICLE VALUE

TELEMATICS	2009			
	NONLUXURY MEDIAN		NONLUXURY INTERQUARTILE RANGE	
	% OF VEHICLES WITH THESE FEATURES	% OF COST PER VEHICLE (FOR THOSE WITH THESE FEATURES)	% OF VEHICLES WITH THESE FEATURES	% OF COST PER VEHICLE (FOR THOSE WITH THESE FEATURES)
DEVELOPED TECHNOLOGIES (E.G., NAVIGATION SYSTEMS, SECURITY SYSTEMS)	30	5	15/42.5	2.5/9
EMERGING TECHNOLOGIES (E.G., TRAFFIC INFORMATION, DROWSY-DRIVER DETECTION)	10	4	5/20	2/7

TELEMATICS CONTENT AS A PERCENTAGE OF VEHICLE VALUE

TELEMATICS	2009			
	LUXURY MEDIAN		LUXURY INTERQUARTILE RANGE	
	% OF VEHICLES WITH THESE FEATURES	% OF COST PER VEHICLE (FOR THOSE WITH THESE FEATURES)	% OF VEHICLES WITH THESE FEATURES	% OF COST PER VEHICLE (FOR THOSE WITH THESE FEATURES)
DEVELOPED TECHNOLOGIES (E.G., NAVIGATION SYSTEMS, SECURITY SYSTEMS)	75	5	50/90	2.5/9
EMERGING TECHNOLOGIES (E.G., TRAFFIC INFORMATION, DROWSY-DRIVER DETECTION)	40	3	25/75	2/6

SELECTED EDITED COMMENTS

- Developments in current technologies will reduce the cost of the features as a percentage of vehicle cost. Thus, features not currently present will be added without significant cost burdens, even on nonluxury vehicles.

- Driver ID, drowsy-driver detection, alcohol level and other insurance or safety-related systems could see widespread use because of insurance or local or federal regulation.
- Emerging technologies may also include radar braking/head using adaptive cruise control, heads-up display, integrated computer terminal (peripherals, etc.). The calculation is based on the option package price. Cost is assumed to be 35 to 50% of retail price.
- Hard to tell what the true value to the customer is. These kinds of options tend to come and go, like the load leveling on the 56 Packard, ABS on my '71 Thunderbird, the talking cars of the '80s.
- Some major barriers exist: 1) driver information overload and 2) little necessity most of the time, at least in N.A. Consequently, entertainment and non-transportation related information services may have more interim potential.
- Some type of security systems are standard on most present-day vehicles. The added cost will be in addition to existing costs.
- This is difficult, because most telematics, information, and communications features will be acquired by car and truck owners in the aftermarket (at prices much less than those available from OEM's) and will be connected to the vehicle using some form of consumer electronics bus (similar to that proposed in AMIC). This is the model followed by cell phones and, in Japan, by navigation systems.
- We're just scratching the surface in this technology area.
- Will emerge sooner in Japan followed by Europe. U.S. will lag behind.

RESULTS SUMMARY

Panelists forecast that developed telematics technologies will be installed on 30 percent of nonluxury vehicles and 75 percent of luxury vehicles by 2009. These technologies are forecast to account for 5 percent of the total cost of the vehicle. Emerging telematics technologies are forecast on 40 percent of luxury vehicles.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi forecast.

STRATEGIC CONSIDERATIONS

Telematics offer a tremendous opportunity for vehicle manufacturers and suppliers. They represent new, high-profit, vehicle content, and the potential applications are expected to expand considerably in the next decade. In addition to telephones, guidance systems, and in-vehicle messaging other applications may include internet access, FAX and E-mail.

Safety is a significant issue with regard to these applications. Designers of these systems will be required to consider this aspect. It is not obvious how many activities a driver can perform without jeopardizing safety. At the extreme, one could argue that the driver cannot perform any activities other than driving the car without compromising safety. We have many years of experience with radios in vehicles. More recently, vehicle telephones have been

added. There is no question that accidents occur in higher frequency because of drivers distracted by telephones. Additional telematics have the potential to add to driver distraction. The issue is how much driver freedom of access can the designer usurp in order to maintain safety. Should the vehicle be required to be at rest in order to operate these devices? Who decides? Who is liable in case of accident? These are questions that manufacturers and suppliers must seriously consider before the application of future telematic systems.

TECH-59 What percentage of North American-produced passenger cars will employ the following electronic and/or electrical features as factory-installed equipment in 2004 and 2009?

ELECTRONIC/ELECTRICAL FEATURES	1998* (%)	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2004 (%)	2009 (%)	2004 (%)	2009 (%)
ANTITHEFT ('95 MY)	30.3	40	55	35/50	45/72.5
AUTO PC ENTERTAINMENT SYSTEMS	n/a**	5	10	3/10	6/25
BRAKE BY WIRE	0.0	1	5	0/5	3/15
CD PLAYER	32.3	45	60	40/50	50/80
CRUISE CONTROL	78.7	80	88	80/85	82.5/91
DRIVE-BY-WIRE (ELECTRONIC THROTTLE CONTROL)	n/a**	5	15	2/10	10/50
ELECTROCHROMIC GLASS	0.0	1	5	0/5	2/10
ELECTRONIC KEYLESS ENTRY	49.4	60	70	56.3/65	65/80
HID (HIGH INTENSITY) HEADLIGHTS	n/a**	10	22.5	5/16.3	11.5/42.5
MINI-DISCS	n/a**	5	12.5	1/10	5/25
VOICE-ACTIVATED/INTERACTIVE CONTROLS	n/a**	5	10	1/10	5/25

*Source: Ward's Automotive Reports, Dec. 28, 1998 and OSAT estimates.
**Baseline information not available.

SELECTED EDITED COMMENTS

- Voice-activated controls (speech recognition) are a requirement to enable PC/infotainment systems and cell phones, both from a human factors (MMI) perspective and a pending legislative perspective (safety issue).

RESULTS SUMMARY

Panelists forecast that the application of many electrical/electronic features as factory-installed equipment will significantly increase by 2009.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the item shown in the following table.

ELECTRONIC/ELECTRICAL FEATURES	MANUFACTURER MEAN	SUPPLIER MEAN
DRIVE-BY-WIRE (ELECTRONIC THROTTLE CONTROL) 2009	37.4	22.3

Panelists forecast a higher application rate of drive-by-wire (electronic throttle control) by 2009 than do suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

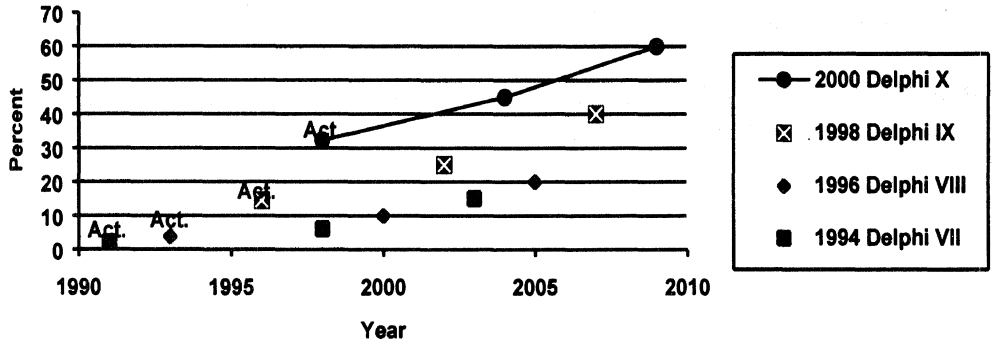
Auto PC entertainment systems, HID headlights, and minidiscs were not covered in a previous Delphi forecast.

Brake by wire and electrochromic glass were covered for the first time in Delphi IX. The results from the current survey and Delphi IX were in agreement.

For the other electronic/electrical features, the results of the current and past forecasts were in agreement with the exception of the following:

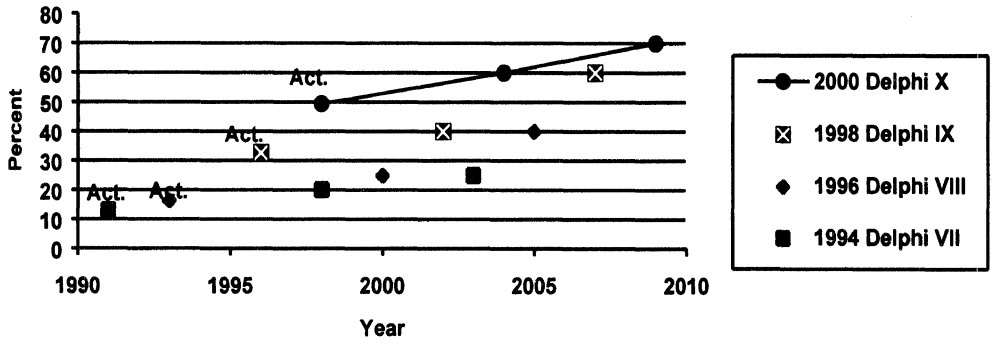
CD player: Application of this feature has proceeded faster than forecast in previous Delphi surveys, as shown in the following graph.

Cd Player Penetration
North American Passenger-Car Production



Electronic keyless entry: Application of this feature has proceeded faster than forecast in previous Delphi surveys, as shown in the following graph.

Electronic Keyless Entry Penetration
North American Passenger-Car Production



Voice activated, interactive controls: The current forecast is for higher penetrations of this feature than previous forecasts. Previous forecasts were for 2 to 4 percent ten years out and 1 percent five years out.

STRATEGIC CONSIDERATIONS

The application of many electronic and electrical features has increased substantially in recent years. Panelists forecast that this increase will continue, and even accelerate, in the next decade. What was recently considered a luxury in a vehicle is now viewed to be a requirement by many vehicle owners. Almost certainly in a few years the list will include features that are unheard of today or are in early phases of research and development. The rapid expansion in this area provides good opportunities for both manufacturers and suppliers.

CD players replace cassette tape decks in many vehicles. On many others, both tape decks and CD players are present.

The key to past expansion in this area has been the rapid reduction in cost and improved capability of systems and components. This cost reduction and performance improvement is expected to continue, and perhaps accelerate, in the future. (See TECH-55). It appears that many customers have the ability to pay for increased vehicle content, in spite of much concern within the industry regarding vehicle affordability. Incidentally, since reaching a low point in affordability in the early '90s, affordability has improved significantly in recent years. This certainly will help enable greater feature content.

Also, the broad interquartile range expressed for a number of these features suggests either significant uncertainty or different strategies on the part of manufacturers.

TECH-60 What percentage of gasoline-powered passenger cars produced in North America will utilize the following systems voltages by 2009?

VOLTAGE LEVEL	MEDIAN RESPONSE	INTERQUARTILE RANGE
	2009 (%)	2009 (%)
12V	60	37.5/80
24V	5	0/15
36V*	10	0/25
12/24V	5	0/14.3
12/36V*	30	4/50

*Commonly referred to as 42V, MIT Study.

OTHER RESPONSES

- 24/200V. 2009: 10%

SELECTED EDITED COMMENTS

- The problem is diminishing returns. Higher voltage systems are going to be more expensive, not less, and will, therefore, follow a niche entry into the market.
- This should be specified/controlled by an industry standards body (SAE or IEEE)

RESULTS SUMMARY

Panelists forecast that 30 percent of passenger cars will have 12/36V electrical systems in 2009. The current 12V system is forecast for 60 percent of passenger cars.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was first asked in this format in the 1994 Delphi VII forecast. Past Delphi surveys have forecast 10 percent or less of system voltages greater than 12V.

STRATEGIC CONSIDERATIONS

The driving forces behind the move to 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 for financial, engineering, and manufacturing reasons. 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-61 How many rotating and linear electric motors will typical standard (i.e., compact, midsized) and luxury North American-produced passenger cars have in 2004 and 2009? Include door locks, mirrors, and trunk-lid actuators. Please provide your estimate for current vehicles. (Table provided as baseline information.)

PASSENGER CAR SEGMENT	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST.	2004	2009	CURRENT EST.	2004	2009
STANDARD (INCLUDE COMPACT, MID-SIZED) <$25,000	30	35	40	23.8/30	28.8/38.5	35/50
LUXURY >$25,000	50	55	70	40/51	50/70	60/90

ELECTRIC MOTOR CONTENT AND CONTROL MODULES MERCEDES S600, CADILLAC STS, NEON			
ELECTRIC MOTOR FUNCTION	1998 MY MERCEDES S600*	1997 MY CADILLAC STS*	1998 MY LOADED NEON*
TOTAL MOTORS	79 Motors	47 Motors	25 Motors

*Source: Joseph F. Ziomek and OSAT estimates from company sources.

RESULTS SUMMARY

The number of rotating and linear electric motors is forecast to increase to 40 for a standard vehicle and 70 for a luxury vehicle by 2009.

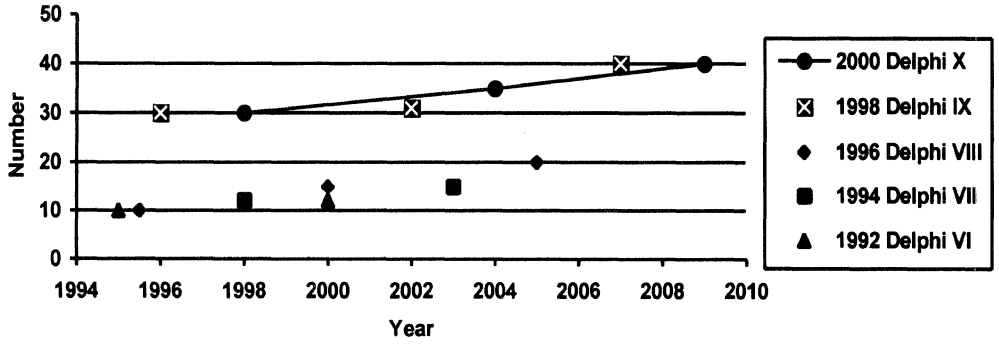
MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers.

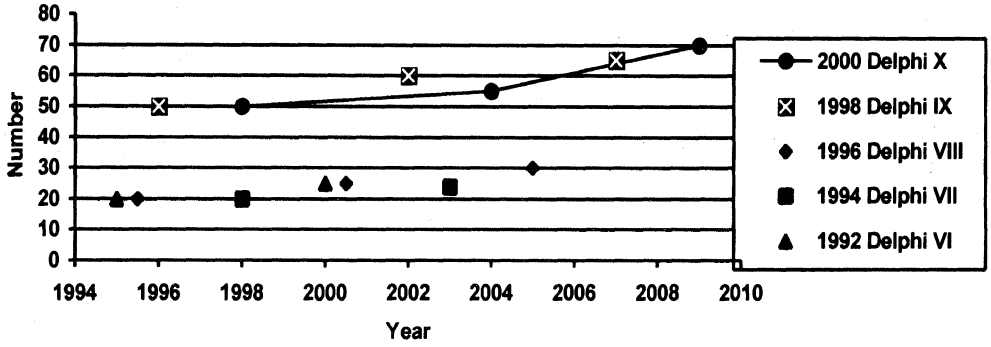
TREND FROM PREVIOUS DELPHI SURVEYS

Results of the current survey are compared with those of past surveys in the following graphs.

Standard Vehicle Electric Motors Forecasts



Luxury Vehicle Electric Motors Forecasts



The current forecast is in line with the most recent forecast, Delphi IX. Both forecasts are well above previous forecasts, however. It is not clear whether this is a result of an actual increase, or the result of more accurate estimates of the current number of motors. Panelists' current estimates are in line with the motor count for Cadillac and Neon supplied by JFZ Associates.

STRATEGIC CONSIDERATIONS

The forecast for an increase in the number of electric motors in a vehicle is good news for motor and motor-component suppliers. It is also good news for vehicle manufacturers from the standpoint of increased high-profit-option penetration.

An increase in the number of electric motors will present challenges to manufacturers, however. Additional motors and their associated features will add weight to the vehicle at a time when manufacturers are looking for ways to decrease weight to improve fuel economy. Also, alternators are at their limit for size and packaging in many vehicles. Additional motors will increase vehicle electrical load. This is further incentive for increased vehicle system voltage, as addressed in TECH-60.

TECH-62 What percentage of North American-produced passenger cars powered by gasoline engines will be equipped with these electric-motor-driven devices by 2004 and 2009? Please provide your estimates for current vehicles.

ELECTRIC-MOTOR-DRIVEN	MEDIAN RESPONSE			INTERQUARTILE RANGE		
	CURRENT EST. (%)	2004 (%)	2009 (%)	CURRENT EST. (%)	2004 (%)	2009 (%)
A/C COMPRESSOR	0	2	10	0/2	1/10	5/20
AIR PUMP	2	5	10	0/10	1.8/15	4.5/25
POWER BRAKES	0.5	5	10	0/3.5	1/10	5/23.8
POWER STEERING PUMP	1	5	15	0/2	2/12.5	8.5/25
WATER PUMP	0	2	5	0/1.5	0/5	1/20

SELECTED EDITED COMMENTS

- Added "efficiency" is unlikely to offset likely higher cost, i.e., development cost, investment, and lack of infrastructure. I would not expect much mainstream migration toward electric drive (for most accessories) except in special situations. However, my lack of enthusiasm for electric accessories/electric steering pump does not apply to electric power steering, which has a very bright future.
- Electric drive is nice, but you have to eliminate all accessory drives in order to realize a real cost saving. The problem is how to drive the alternator without the accessory drive.
- High-voltage systems open up major possibilities for electric-drive accessories.
- How about electric-operated engine intake and exhaust valves?

RESULTS SUMMARY

Electric-motor-driven A/C compressor, air pump, and power brakes are forecast to have penetrations of 10 percent by 2009. Electric-motor-driven power-steering pumps and water pumps are forecast at 15 percent and 5 percent, respectively, in the same time frame.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

CURRENT ELECTRIC MOTOR-DRIVEN:	MANUFACTURER MEAN	SUPPLIER MEAN
AIR PUMP CURRENT	16.7	5

Manufacturers estimate a higher penetration of electric motor-driven air pumps currently than do suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

Results of the current survey are in general agreement with past surveys for air pumps and power brakes. Results of the current survey are 3 to 5 percent higher than past surveys for A/C compressor, power steering pump, and water pump.

STRATEGIC CONSIDERATIONS

The incentive for driving these components with electric motors is that the devices can be used only when needed. This reduces parasitic losses and improves fuel economy.

As noted in the previous question, alternators are at their limit for size and packaging in many vehicles. Additional electric motors will increase vehicle electrical load. This is further incentive for increased vehicle-system voltage, as addressed in TECH-60.

Panelists' comments here should be especially noted, as they address some key issues regarding electric-motor-driven devices.

VIII. OTHER ISSUES

TECH-63 Please forecast the percentage of North American-produced passenger-cars that will have the following maintenance and durability features by the years 2004 and 2009.

VEHICLE MAINTENANCE FEATURES	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2004	2009	2004	2009
	(%)	(%)	(%)	(%)
10-YEAR-BODY-CORROSION WARRANTY (PERFORATION)	50	75	40/50	68.8/80
50,000-MILE/5-YEAR COOLANT	50	75	40/50	63.8/80
100,000-MILE MAINTENANCE-FREE ENGINE (EXCEPT OIL & FILTERS)	50	75	38.8/50	53.8/80
100,000-MILE MAINTENANCE-FREE TRANSMISSION (INCLUDING FLUIDS)	50	75	38.8/50	60/80
100,000-MILE/10-YEAR EXHAUST SYSTEM	30	60	25/40	45/75
CHASSIS LUBED FOR LIFE OF VEHICLE	50	78	40/60	60/90
CHIP-PROOF WINDSHIELD	10	20	5/10	10/26.3

OTHER RESPONSES

- 10-year battery life. 2004: 25%; 2009: 35% (based on responses to Tech-7)
- 100,000-mile air-conditioning systems. 2004: 5%; 2009: 15%
- Emissions-durability legislation is the wild card here. If long term conformance to very strict emissions regulation is required, 100,000-mile/10-year powertrains could become a de facto requirement.
- Exhaust system being forced by EPA. Muffler portion only piece excluded, but small due to more catalyst volume.
- Extended oil/lube/filter >= 10K; 2004: 5%; 2009: 15%
- Greater than 12,000-mile oil-change intervals. 2004: 2%; 2009: 15%
- I am unclear what chip-proof means. Here in Michigan we get pieces of overpasses dropping down and killing drivers, and lots of shucked truck tire treads wiping out windshields. Perhaps improved chip and crack resistance?
- Longer-life HVAC filters. 2004: 10%; 2009: 25%
- Nationwide inspection. 2004: 0%; 2009: 5%
- Oil-condition monitor vs. algorithm. 2004: 2%; 2009: 5%
- The problem with low or no maintenance is that the dealers and parts stores go broke. These guys have more clout than the consumers do or EPA does in Congress, so look for legislation that encourages clean, reliable vehicles that still require repairs.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

VEHICLE MAINTENANCE FEATURES	MANUFACTURER MEAN	SUPPLIER MEAN	MANUFACTURER MEDIAN	SUPPLIER MEDIAN
100,000-MILE/10-YEAR EXHAUST SYSTEM 2004	39.0	30.6	35.0	30
CHIP-PROOF WINDSHIELD 2009	16.5	25.0	20.0	20.0

Manufacturers forecast a somewhat higher application of 10-year exhaust systems for 2004. The two are in agreement for 2009, however.

Suppliers are more optimistic regarding application of chip-proof windshields than are manufacturers for 2009. Considering that this is an emerging application, this difference in forecasts 10 years out may not be unexpected.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was first asked in the 1998 Delphi IX forecast. There is very good agreement between the two forecasts for all features.

STRATEGIC CONSIDERATIONS

Reducing required vehicle maintenance offers the opportunity to improve customer satisfaction and owner loyalty. The manufacturer that can offer these maintenance features at low or no cost to the customer will be in an advantageous position. It is likely that customers will consider many of these features as a standard requirement in 2009.

The panelists' comments regarding dealer influence and emissions durability legislation should be noted, as they could affect the future of many of these features. These comments address potentially conflicting forces. With the industry, in particular, dealers may begin to exert influence in regulatory areas that once were the sole concern of manufacturers and suppliers.

The changes forecast could have a profound impact on the traditional aftermarket and service sector and suggest the service-reduction revolution will continue. It's instructive to consider where we were 30 to 40 years ago, when we changed oil every 1,000 miles, spark plugs 10,000 miles, ignition system components regularly, and tires lasted only 20,000 to 25,000 miles. Those were the good old days?

TECH-64 What new technologies that have not already been 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?

Body:

- "Chameleon" paints.
- All-plastic bodies (2 comments).
- Compliant/dent-resistant body panels.
- Energy-absorbing structure/material for interior.
- Four-piece molded body construction (DaimlerChrysler).
- HVAC and instrument-panel modules.
- Hybrid frames, plastic glued to steel.
- Injection molded semistructural thermoplastic bodies.
- Mass reduction.
- Mobile multimedia (entertainment, information, and communications).
- Plastic for class A surfaces.
- Some new technologies include tailored blank and hydroformed structure, extensive aluminum substitution, and aerodynamically adjusting shapes.
- Tubular body space frame utilizing hydroforming processes.

Chassis:

- Aluminum substitution and more compact suspension.
- Composites.
- Electronic stability control.
- Engine-cooling modules.
- Extensive use of aluminum for wheel end-knuckles and suspension-control arms. Replace subframes with a single hydroformed crossmember for the powertrain and steering/suspension component support.
- Magnesium and titanium suspension components.
- Modular chassis systems.
- Multilink suspension.
- Smart component in the chassis, i.e., Continental Smart Tires.

Electrical:

- 115V inverter.
- Based on ABS systems include computer intervention with engine, brake system, transmission and transfer case. Brake by wire. Steering by wire.
- Both electrical and optical transputers could radically change electrical-system-architecture philosophies.
- Control by wire.
- Electronic transmission shift control, thermoelectric heating, cooling, and power generation, increased use of subsystem modeling for controls.
- Flywheel/alternator/starter (enabler for engine off at idle) (2 comments).
- Information systems.
- Integrated vehicle electrical/electronic systems.
- LED, laser, fiber optic.
- Lightweight, high-torque electric motors.
- Optical MPX for entertainment and control.
- Standardization of information bus protocols; E/E system bus interface protocol (wiring/connectors and software interfaces) for plug-and-play.
- Technologies such as vehicle true position and active braking and steering are emerging.

Fuels and Fluids:

- Alternative fuels.
- Biofuels.
- Coolants, refrigerants.
- Fuel cells.
- Improved, low emission-type reformulated fuels; CNG and LPG usage.
- Industry standards for gas, diesel, and alternative fuels.
- Long life.
- Longer-life oils.
- Low-sulfur fuel?
- Methanol.
- No-service fluids (not including engine oil).
- Synthetic coolants and lifetime lubricants.
- Zero-weight oils.

Powertrain:

- Advanced engine-management systems.
- California LEV-II standard and US EPA tier-two emissions regulation.
- Camless, electrically operated valvetrains (5 comments).
- Catalyst technology.
- Continued new internal combustion engines, ultracompact and low profile V-8's, and gasoline or alcohol reformers (fuel cells). CVT transmissions may even be used for regenerative brakes. See Electrical/Electronics.
- Cylinder deactivation returns (2 comments).
- DI diesel (vs. emissions).
- Diesel engine NOx catalysts; plasma catalysts.
- Electronic turbochargers; in-cylinder emission control; plastic structures.
- Four-wheel drive connection systems, hub locks.
- Hybrid systems for better emissions and mileage control (4 comments).
- Integrated alternator/starter/damper (2 comments).
- Other CVT technology, turbine.
- Stratified charge gasoline engines, novel diesel catalysts.
- UHEGO, new spark plug, electronic throttle control.
- Vastly improved combustion. Lightweight engine and alternate -CNG % LPG fuelled engines and CVT.

Safety:

- Additional crash protection and crash-avoidance technologies.
- Advanced safety interiors.
- Anticipatory radar crash sensors.
- Electric brakes.
- Smart airbag system; adjustable pedals.

Tires/wheels:

- Larger wheels with low aspect ratio tires.
- Load, air-pressure, and temperature sensing.
- Smart tires.
- Tires at 100,000 miles (2 comments), lower drag.

Other:

- Add-on electronics via the vehicle MPX bus.
- ITS and AHS technologies will emerge as significant new technologies.
- Noise reduction.
- On-board personal computers.

- SAE, IEEE, and other foreign automotive/electrical-standards bodies need to consolidate forces to drive global regulations to 1) enable cost-effective technology into the vehicles, and 2) to decouple the longer vehicle-development cycles from those of the consumer electronics industry (which has a much faster product cycle).
- Smart sensors and actuators.
- Some AWD with true ground-speed control.
- Virtual engineering. 3D CAD and CAE with live video communication.

RESULTS SUMMARY

Panelists have noted many additional new technologies that may have an impact on the automotive industry in the next decade.

MANUFACTURER/SUPPLIER COMPARISON

This comparison is not made for open-ended questions.

STRATEGIC CONSIDERATIONS

Many or most of the new technologies listed by panelists are currently under development. The manufacturer or supplier that is able to bring these technologies to market may have a competitive edge in the next decade.

Certainly the next decade is going to be challenging and interesting as a myriad of technology innovations are developed and brought to market.

TECH-65 Please indicate your estimate of human-resource scarcity for the following entry-level positions currently and in 2009.

SCALE →	1	3	5
	SEVERE SCARCITY	MODERATE SCARCITY	NO SCARCITY

OCCUPATION	CURRENT RATING	2009 RATING
	MEAN RESPONSE	MEAN RESPONSE
ENGINEER		
CHEMICAL	3.3	2.9*
ELECTRICAL	2.6	2.3*
INDUSTRIAL	3.4	3.1*
MANUFACTURING	2.8	2.7
MATERIALS	3.1	2.7*
MECHANICAL	3.1	2.9*
SYSTEMS	2.5	2.3*
DESIGNER	3.0	2.8*
SOFTWARE PROGRAMMERS/ENGINEERS	2.3	2.3
CAD/CAM/CAE OPERATOR	2.6	2.6
ELECTRONICS TECHNICIAN	2.8	2.6*
SERVICE TECHNICIAN	3.0	2.7*
SKILLED TRADES	3.1	2.7*

*Indicates significant difference in current/2002 comparison.

SELECTED EDITED COMMENTS

- Competition with other industries for a limited number of technically trained workers will impact the automotive industry and may limit its rate of growth or change.
- Engineers will continue to be the easiest skill resource to acquire, but hands-on people will continue to be in short supply. As advanced technologies diffuse into the developing world more and more, their available pool of high-tech technicians will grow and moderate the domestic shortage.
- Software- and powertrain-calibration people will be in great demand as the industry embraces new technology for emissions reduction and fuel economy simultaneously.
- There is presently, and will be for a significant period of time, a very severe shortage of women and underrepresented minorities in engineering and science. Especially with advanced degrees. There is also a growing shortage of U.S. born graduates in mechanical engineering, systems, CAD/CAM/CAE and electrical engineering.

RESULTS SUMMARY

Panelists note a moderate scarcity of people in many technical disciplines currently, and forecast that this scarcity will increase somewhat in the next decade.

MANUFACTURER/SUPPLIER COMPARISON

There are no statistically significant differences in responses between manufacturers and suppliers with the exception of the items shown in the following table.

OCCUPATION	MANUFACTURER MEAN	SUPPLIER MEAN
ENGINEER		
MATERIALS CURRENT	3.4	2.7
MATERIALS 2009	3.0	2.4
SYSTEMS 2009	2.5	2.0
SKILLED TRADES 2009	3.0	2.4

TREND FROM PREVIOUS DELPHI SURVEYS

This question was first asked in the 1996 forecast Delphi VIII. There is very good agreement between the current and past two forecasts. The greatest spread in responses for any occupation between the three forecasts is 0.3 rating points. The average spread is less than 0.1 rating points.

STRATEGIC CONSIDERATIONS

The ability for manufacturers and suppliers to compete in the marketplace is affected greatly by the availability of qualified technical people. Panelists rate the scarcity of all disciplines as at least moderate currently, and forecast that this scarcity will be slightly more severe in 2009. This poses problems for manufacturers and suppliers.

One of the panelists commented that there is also a growing shortage of U.S.-born graduates in mechanical engineering, systems, CAD/CAM/CAE and electrical engineering. This is particularly true of advanced-degree recipients in these areas. There is a tremendous competition between areas of study for the most talented high-school graduates. The lure of wealth on Wall Street and in business in the areas of finance, business management, and e-commerce draws many top students. Other areas of competition that are perceived as more lucrative financially are law and medicine.

Many advanced-degree recipients in technical fields are foreign born. Many of these graduates remain in this country and work in the automotive industry. Many do not remain here, but return to their home countries. It is a strategic advantage for North American-based organizations that North America is viewed as the educational mecca for students from all over the world. Access to these young professionals is critical as skilled human-resource shortages become more acute. It is important that industry also find ways to attract the most talented students from North America to the technical fields. This may be through increased pay levels, or improvements in the work atmosphere in the automotive industry similar to those found in other high-tech industries or in other fields of work such as finance.

Industry should become increasingly involved in the education process in order to promote interest in the sciences and technical fields. A student's interest in a field of study may be shaped early in his or her life. It is important that the technical fields are presented in a positive, interesting, and exciting manner to the most talented students. This is a challenge for the future to both industry and the educational institutions. We all have a role to play in selling the automotive industry as an industry of future opportunity and value to society. No

longer should the industry be viewed as characterized by smoke stacks and rust. It is particularly important to communicate more effectively with teachers, counselors, media and parents.

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DEFINITIONS

BIG THREE. Refers to Ford, GM, and DaimlerChrysler.

CAFE. Corporate average fuel economy is based on all vehicles sold in the United States by a corporation. DaimlerChrysler will now have one CAFE value for cars and one for trucks.

EUROPEAN INDUSTRY. Includes functions and activities performed in Europe regardless of headquarters location or ownsership, e.g., Opel and Saab in Europe.

JAPANESE INDUSTRY. Includes functions and activities performed in Japan regardless of headquarters location or ownership, e.g., Mazda and Toyota in Japan.

LIGHT TRUCK. Includes sport utilities, vans, and pickup vehicles less than 6,000 lb. GVW.

NORTH AMERICAN INDUSTRY. Includes functions and activities performed in North America regardless of headquarters location or ownership, e.g., Honda design in California and BMW production in South Carolina.

PNGV. Partnership for a New Generation of Vehicles.

Notes: "Year" refers to Model Year unless otherwise specified.

Installation rates for 1998 include production in the United States, Canada, and Mexico for the United States Market.

"Current Vehicles" refers to Model Year 1998 unless otherwise specified.

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KEY WORD INDEX

KEY WORD INDEX

KEY WORD	TECHNOLOGY QUESTION
Drivetrain	54
Drivetrain configurations	9,54
Drowsy-driver detection	58
Dual overhead cam	41
Durability	63
EPA	49b
Electric	6,8
Electric drivetrain	9,11
Electric motors	11,61,62
Electric power plant	6
Electric vehicle	7,11
Electrical	33,55,59,64
Electrochromic glass	59
Electronic controls	4,33
Electronic keyless entry	59
Electronic systems	55,59
Electronics technician	65
Elimination of labor	26
Emerging technologies	14,58,64
Emission absorbers	49a
Energy storage	4
Engine	9,38,39,40,41,42,43, 44,45,46,47,51,62,63
Engine block	47
Engine controls	49a
Engine efficiency	4
Engine head	47
Engineering	15
Engineering duplication	26
Engineers	65
Environment	14
Ergonomics	14
Europe	3,16,19,20

KEY WORD	TECHNOLOGY QUESTION
Evaporative controls	49a
Exhaust system	63
Exterior panels	29
Federal Standards	48
Four-cylinder	43
Frame constructions	31
Front fenders	29
Fuel cells	6,9,49a
Fuel economy	4,14,27
Fuel injection	44
Fuel prices	1
Fuel-rails	51
Fuels	6,49a
Fuels and fluids	64
Gas turbine	8
Gasoline prices	1
GDI	44
Glass	28
GPS	37
HID (high intensity) headlights	59
HVAC control	57
Handling	57
Hardpoints	19
Hollow camshaft	42
Hood	29
Human resources	65
Hybrid electric combustion engine	6,8
Hybrid powertrains	4,10
Hybrid vehicle	7,11,49a
Ignition system	46
Ignition timing	49a
In-line	41
In-line (IL-6)	39
Individual cylinder control	49a
Information technology	58

KEY WORD INDEX

KEY WORD INDEX