DELPHI VII FORECAST AND ANALYSIS OF THE NORTH AMERICAN AUTOMOTIVE INDUSTRY

VOLUME 2: TECHNOLOGY

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Foreword and
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FOREWORD

Introduction

Delphi VII 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 and marketing. These individuals were selected because they occupy positions of responsibility within the automotive industry and have strategic insight into important industry trends. In many cases they are in a position to influence these trends. This report, published in three volumes, is the seventh 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 and Delphi VI in 1992.

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

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

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

The Delphi method: general background

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

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

Process

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

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

In the Delphi method, panelists respond anonymously, preventing the identification of a specific opinion with any individual or company. This anonymity also provides the comfort of

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

Panel characteristics and composition

The very essence of a Delphi survey is the careful selection of expert respondents. The selection of such experts for this Delphi survey is made possible by the long-standing association between The University of Michigan faculty/staff 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 227 member panels are as follows: 10 percent of the Technology Panel were composed of CEOs, presidents, or vice presidents; 22 percent were directors; 23 percent were managers or supervisors; 42 percent were engineers (chief, assistant chief and staff); and 3 percent of the panel were made up of academic specialists and consulting technical-engineering specialists. The Marketing Panel was composed of 29 percent CEOs, presidents, or vice-presidents; 22 percent directors; 39 percent managers; 3 percent engineering specialists; and 7 percent academic and consulting marketing specialists. Among Materials panelists, 14 percent were CEOs, presidents and vice presidents; 12 percent were directors; 51 percent managers and supervisors; 16 percent engineering specialists; and 7 percent academic and consulting materials specialists. Approximately 34 percent of the Delphi VII panelists were employed by vehicle manufacturers; 56 percent by components and parts suppliers; and 10 percent were specialists, consultants and academics.

Presentation of Delphi forecasts and analyses

Data Tables. When a question calls for a response in the form of a number, responses are reported as the median value and the interquartile range (IQR). The median is a measure of central tendency that mathematically summarizes an array of judgmental opinions while discounting extremely high or low estimates; it is simply the middle response. The IQR is the range bounded at the low end by the 25th-percentile value, and at the high end by the 75th-percentile value. For example, in a question calling for a percentage forecast, the median answer might be 40 percent and the IQR 35-45 percent. This means that one-quarter of the respondents answered 35 percent or less, another one-quarter chose 45 percent or more, and the middle half of all responses ranged between 36 percent and 44 percent, with 40 percent as the middle response. That narrow interquartile range would indicate a fairly close consensus among the respondents.

In contrast, the percentage forecast for a different question might show a similar median forecast of 40 percent, but with an interquartile range of 20-70 percent, indicating less consensus and a considerable degree of uncertainty about the issue in question. Sub-group median estimates will not necessarily add to 100 percent, except in the case of a normal distribution.

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

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

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

In a Delphi survey, respondents are encouraged to contribute comments to explain their forecast and to perhaps persuade other respondents to change their positions. Many of these edited comments are included. These replies may provide important information which is not evident in the numerical data. An individual panelist may have unique knowledge that planners

should carefully consider. However, readers should be careful not to overemphasize a particular comment. It is possible for a well-stated contrary opinion to mislead the reader into ignoring an important majority opinion which is accurately reflected in numerical data.

Manufacturer/Supplier Comparison. Delphi VII 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 Manufacturer (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 between the opinions of these two groups.

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

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

Trend from Previous Delphi Surveys. A single Delphi survey is a snapshot which collects and presents the opinions and attitudes of a group of experts at a particular point in time. Some questions, in various forms, were asked in previous Delphi surveys, and thus provide trend data. The fact that forecasts for a particular question may exhibit considerable variation over the years does not diminish its relevance and importance to strategic planning, because it reflects 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 VII 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 face formidable challenges in the next decade as they address environmental issues, tough global competition and more demanding customers. Furthermore, shortages of capital and skilled human resources and time pressures to do more, better, yet faster, exacerbate their challenges. *The Delphi VII Forecast and Analysis of the U.S. Automotive Industry: Technology* survey identifies many issues facing the industry and provides insight as to industry direction. In a real sense, this is a benchmarking study in that it enables any one individual or organization to compare (benchmark) its vision of the future to an industry consensus vision. Panelists expect rapid changes in technology and knowledge as well as increased regulation and accelerating globalization. Increased reliance on technology to enhance design and manufacturing efficiency is anticipated. Organizations that effectively develop and implement this rapidly changing technology to reduce cost and improve customer satisfaction (increase value) will certainly have a competitive advantage.

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

Strategic Planning Factors. Emissions, fuel economy, and safety standards are expected to be more restrictive over the next 10 years. Fuel prices are expected to increase steadily, but moderately, to $1.75 per gallon for regular unleaded gasoline by 2003. High concentration alcohol and natural gas fueled vehicles are expected to comprise 5 percent and 2 percent, respectively, of North American-produced passenger cars and light trucks by 2003. Electric vehicle penetration is forecast to be 1 percent in the same time frame. Increased cooperation between traditional North American manufacturers and between traditional manufacturers and suppliers is expected, as is cooperation between government and industry.

CAFE standards are expected to increase approximately 20 percent by 2003 for both passenger cars and light trucks and vans to 32 mpg and 25 mpg, respectively. This is in contrast to stable passenger car CAFE standards of the past four years, and an increase of only 5.8 percent in the last 10 years. The prospect for increased CAFE standards will present a major challenge to all manufacturers.

Considering the recent agreement of the domestic manufacturers and the federal government to develop clean, super-efficient cars, panelists forecast a fuel economy of 45 mpg would be possible for an advanced technology five-passenger car for 2020—far short of the stated goal of 87 mpg.

Engineering and Sourcing Issues. Panelists believe that 80 percent of product design and engineering by traditional domestic vehicle manufacturers for North American-produced passenger cars will be done in North America in 2003 compared to 90 percent today. Foreign-based vehicle manufacturers are expected to conduct 25 percent of their product design and engineering for North American-produced passenger cars in North America compared to 10 percent today.

Traditional domestic manufacturers are forecast to source the majority (74 percent in 2003) of parts, components and subassemblies from the United States, Canada and Mexico in the next decade. An increasing percentage is expected to be sourced outside of North America, however, including increases in Southeast Asia and Eastern Europe. North American production operations of Japanese-owned vehicle manufacturers are expected to continue sourcing a significant fraction of parts, components and subassemblies from Japan over the next decade. An increasing percentage is forecast to be sourced in North America, however (35 percent in 2003 vs. 25 percent today). Sourcing from Southeast Asia is also expected to increase, as was true for domestic manufacturers. Traditional domestic and foreign manufacturers are expected to expand their Mexican component and subassembly sourcing from 10 percent today to 20 percent by 2003.

Panelists forecast a substantial reduction in the product development time of a new platform for both the Japanese and U.S. manufacturers in the next decade. The Japanese advantage is expected to be greatly reduced from 12 months currently to four months by 2003.

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

Emerging Technology and Technology Issues. Advances in computer technology and software, and better use of currently available technology and software, are expected to have substantial influence on improved product cycle timing and total vehicle cost. These advances

will be used throughout the process of vehicle design, development, manufacture and sale. The rapidly developing science of information technology is expected to be a key factor in the engineering of future products. It requires careful watching.

"Smart" materials, including electrorheological fluids and electrochromatic glass, are expected to see some limited application by 2003.

The vehicle design theme of "cab forward" is forecast to be used in 50 percent of North American-produced passenger cars by 2003.

Materials and Recycling. Panelists forecast reductions in steel and cast iron use of 18 percent and 30 percent, respectively, and increases in the uses of aluminum and plastics/composites of 58 percent and 31 percent, respectively, in the next decade if CAFE increases to 35 mpg. This shift from high- to lower-weight materials is prompted by anticipated increases in fuel economy requirements. The use of aluminum and plastic for exterior body components is expected to increase substantially in the next decade, but steel should remain the dominant material.

An 8 percent total weight reduction is envisioned by 2003, and the value of a pound of weight saved in a vehicle is forecast to escalate from $2.00 per pound today to $4.00 per pound in 2003, assuming a CAFE requirement of 35 mpg in 2003.

Panelists rate the barriers to recycling of ferrous metals of minor significance; non-ferrous metals as somewhat important; but thermoplastics and thermoset polymers and automotive fluids as more challenging, depending on the compound. Federal and/or state regulatory activity of recyclability is expected.

Expected modifications of used vehicles to accommodate non-CFC refrigerants vary from minor to major to not possible.

Body and Chassis Product Trends. The integral body/frame is expected to remain the major vehicle platform through 2003, although spaceframe construction is forecast to increase from 3 percent today to 5 percent by 2003. Vehicle structural stiffness is expected to be somewhat increased, particularly for less rigid vehicles in the next decade.

MacPherson strut front suspensions are expected to dominate (65 percent in 2003), but increased penetration of twin A-arm is forecast for passenger cars. Rear independent suspensions in passenger cars is forecast to increase. Electrical/electronic power steering and hydraulic power steering with electronic control are expected to see some use compared to none today. Passive-driver selected semi-active and active suspensions are expected to attain penetrations of 5 percent, 8 percent and 3 percent, respectively, by 2003.

Antilock brake penetration on passenger cars is forecast to approach 100 percent during the next decade while traction control is expected to see an application rate of 20 percent in the same time frame.

Panelists forecast that the minispare will continue to be dominant (90 percent in 2003), with limited use of the currently identified alternatives. A small but growing application of tire failure sensing devices (10 percent), puncture resistant tires (15 percent) and run-flat tires (10 percent) is forecast by 2003.

Safety. Driver side airbags are expected on all passenger cars and 95 percent of light trucks in 2003. Passenger side airbags are forecast on 90 percent of passenger cars and 50 percent of light trucks. Modest use of rear seat occupant and side airbags is also expected in passenger cars but not on light trucks. Other safety features such as in-vehicle message systems and collision warning systems are envisioned in limited numbers over the next 10 years.

Powertrain/Drivetrain. For passenger cars, eight-cylinder engine usage is forecast to decline for the next decade, with both four- and six-cylinder engine penetration increasing slightly. Similar trends are forecast for light trucks, but with eight-cylinder engine usage at more than twice that of passenger cars. Modest engine displacement reduction is expected in the next decade for both passenger cars and light trucks.

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

Diesel engines are not envisioned for passenger cars in the next decade, but their use in light trucks is expected to increase from 3 percent in 1992 to 7 percent in 2003.

The future role of two-stroke gasoline engines is uncertain but they are still forecast to be in 3 percent of passenger cars by 2003. The size, weight and potential cost advantages of this engine are attractive, but emission control and noise are viewed as significant problems.

Port fuel injection is forecast in 95 percent of passenger cars with spark ignited engines by 2003 compared to 23 percent in 1991. In contrast, throttle body injection is expected to essentially disappear. Direct cylinder gasoline injection could make an appearance by 2003.

Turbocharging and supercharging are expected to be minimal at only 1 percent of passenger cars by 2003. On the other hand, four-valve-per-cylinder engines are expected on 35 percent of passenger car engines compared to 13 percent in 1992. The increase in multivalve engines is certainly a factor in the low expectations for turbochargers and superchargers. It is interesting to note that the forecasts for multivalve engines is considerably less in Delphi VII than observed in our 1989 and 1992 surveys.

From 1992 to 2003, pushrod valve actuation penetration is expected to decrease from 55 percent to 35 percent while single and dual overhead cam penetrations are forecast to expand to 40 percent and 20 percent, respectively, by 2003. Variable valve timing and lift control are forecast at 20 percent and 10 percent respectively, in 2003.

Spark-ignited engines are expected to see increases in use of distributorless ignition systems, individual cylinder spark control, cylinder pressure control and knock adaptive control of ignition in the next decade. Furthermore, features such as balance shafts, fast-burn combustion chambers, hollow camshafts and roller lifters are all expected to expand in the next decade.

Use of aluminum cylinder heads and blocks in passenger car engines is expected to increase dramatically to 80 percent and 35 percent respectively, by 2003. Several applications of plastic engine components are expected to see significant use (inlet manifolds, valve covers), while ceramic engine components are forecast to see limited application by 2003.

Pre-heated catalytic converters and NOx catalysts are believed to be required in some applications to meet both federal and California emission standards over the next decade.

The five-speed is expected to be the only manual transmission with any significant volume in the next decade. The decline of the three-speed automatic transmission is expected to continue in favor of four speed designs, but should be used in significant numbers by 2003 (10 percent). Five-speed automatic transmissions are forecast to emerge in upscale vehicles (10 percent). Electronic control is expected to become almost standard (90 percent) by 2003.

In the opinion of our panelists, front engine, front drive will be the dominant drivetrain configuration in passenger cars (89 percent). Of these, 94 percent are expected to use transverse engine mounting in 2003.

Electrical/Electronics. Vehicle electronic content is expected to continue its rapid growth, from a 1991 estimate of 10 percent total vehicle value to 20 percent by 2003. Vehicles with at least one major multiplexed power system are forecast to expand from a current market estimate of 1 percent to 10 percent by 2003. Some use of fiber optics will be used in the control, but significant economic and technical problems must be resolved. Packaging and weight reduction are the important advantages of multiplexing.

Electronic/electrical features such as antitheft, CD player, electronic keyless entry and onboard diagnostic via expert systems are expected to increase significantly in the next decade. Considerable interest is expressed for an increase in vehicle electrical system voltage, but no significant application rate is forecast in the next decade. An increase in the number of electric actuator motors of over 50 percent is anticipated by 2003.

Other Issues. Service activity in dealerships is expected to increase modestly in the areas of electrical/electronics and non-CFC refrigerant conversion. Body shop service is forecast to remain unchanged, while general mechanical service is expected to decline in the next decade.

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

Vehicle integration is rated as a very significant concern as more components are engineered by suppliers, and this area will require close attention in the next decade.

Panelists expect environmental and fuel economy issues to be the greatest technological challenges of the next decade. Cost reduction and flexibility are viewed as the greatest manufacturing challenges.

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Strategic Planning Factors

TECH-1 Please estimate U.S. retail fuel prices, per gallon, for 1998 and 2003, including fuel tax. (Please use constant 1993 dollars without adjusting for inflation.)

		Median Response		Interquartile Range	
Unleaded Gasoline	Est. 1992*	1998	2003	1998	2003
Regular	$1.10	$1.40	$1.75	$1.30/1.50	$1.50/2.00
Premium	$1.29	1.70	2.00	1.50/1.80	1.70/2.25

* **Source:** AAA December 1992 Survey. This was provided to panelists as a baseline.

Selected edited comments

- Fuel prices will still be very low compared to Western Europe and Japan.
- Government will force higher prices due a to greater world pressures.
- Growing environmental concerns will prompt gasoline tax increases to reduce demand and fund research (alternate fuels, electric vehicles).
- I believe that grades of gasoline will vanish.
- Increased fuel tax should account for the greatest part of the increase. The cost differential should become smaller between regular and premium due to greater increase of premium required for future vehicles.
- Increased taxes will account for most of the increase.
- Tax is a politically driven and decided component of price. These are trend line projections. Special events may drive prices above the trend line for one to three years. Ultimately, increased demand and the need to get oil from remote and difficult places will overwhelm improved finding and producing technology; then prices will rise.

Discussion

This question has been asked in much the same form since the first Delphi study in 1979. The price and availability of gasoline is a significant factor in the design of future vehicles and the projection of vehicle mix.

Current survey panelists anticipate that the price of gasoline will increase at a compounded rate of 4.0-4.6 percent per year in constant 1993 dollars for the time periods in question.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement with the exception of the forecast for regular gasoline in 2003. Manufacturers forecast $1.60 per gallon compared to $1.85 for suppliers.

Comparison of forecasts: MKT-3 and MAT-1

Results for the technology, marketing and materials surveys are summarized in the following table.

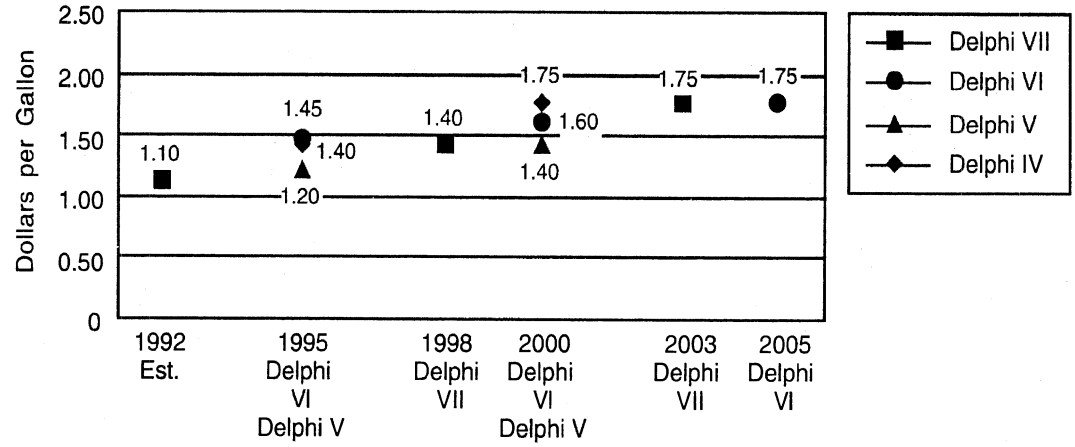
Unleaded Gasoline	Est. 1992*	Median Response					
		1998			2003		
		TECH	MKT	MAT	TECH	MKT	MAT
Unleaded regular	$1.10	$1.40	$1.45	$1.35	$1.75	$1.70	$1.68
Unleaded Premium	$1.29	1.70	1.60	1.55	2.00	1.90	1.85

* **Source:** AAA December 1992 Survey. This was provided to panelists as a baseline.

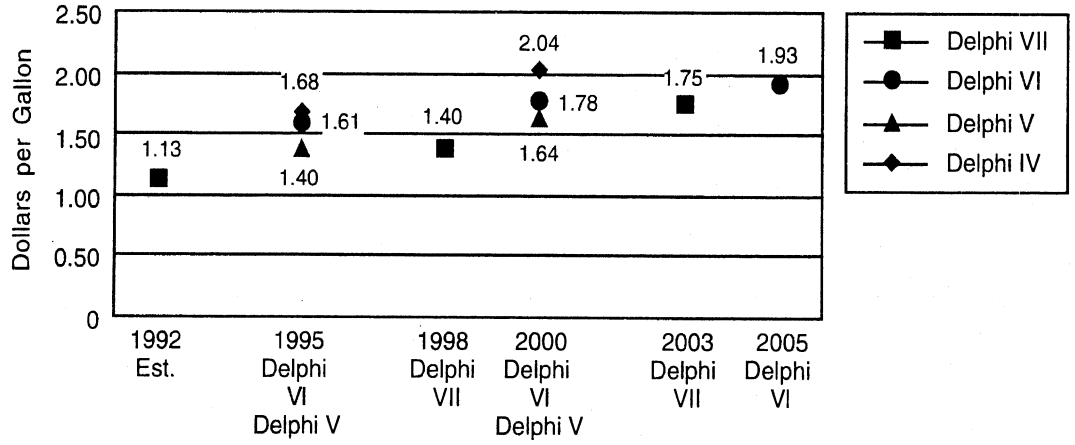
Trend from previous Delphi surveys

The following graphs compare the prices of gasoline for this and the previous three Delphi forecasts in dollars at the time of the survey and also in constant 1993 dollars.

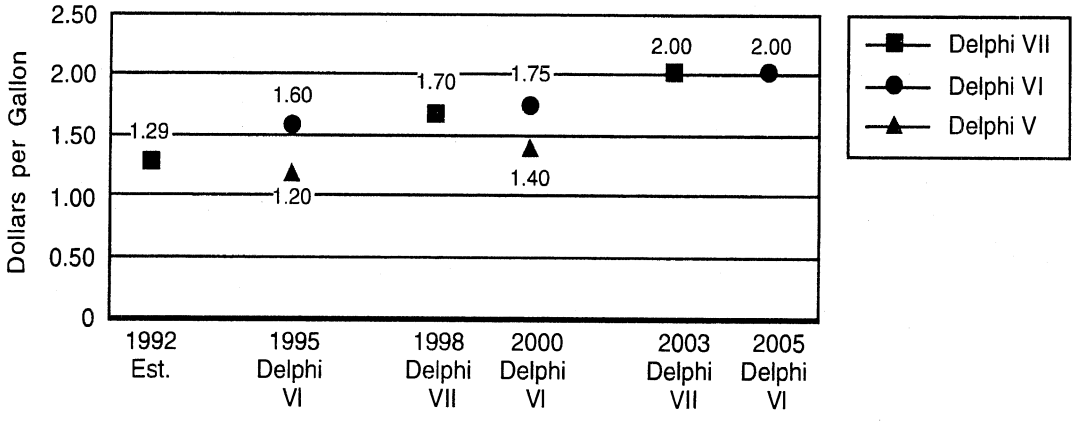
Regular Fuel Price Forecasts
(Price at Time of Survey)

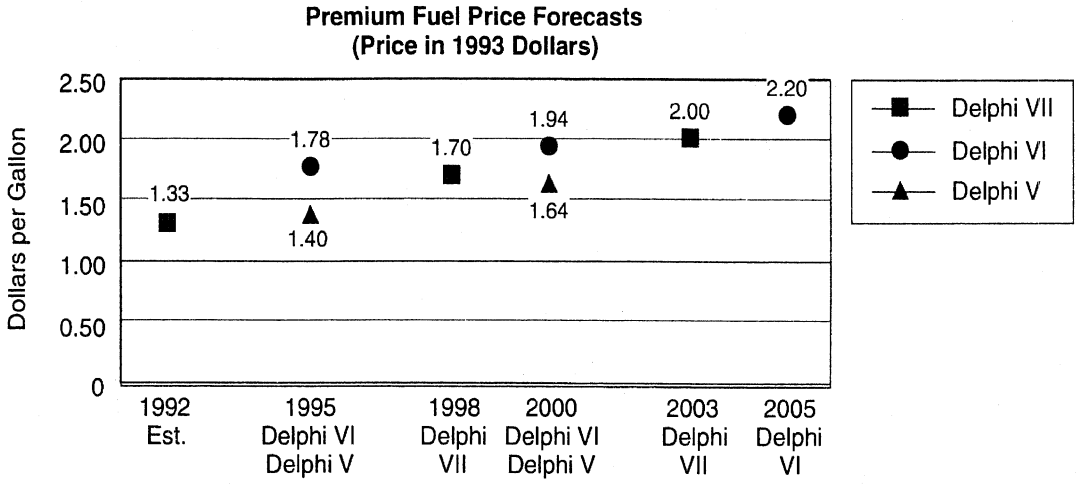


Regular Fuel Price Forecasts
(Price in 1993 Dollars)



Premium Fuel Price Forecasts
(Price at Time of Survey)





Fuel prices and forecasts for the future have stabilized or shown a moderate upward trend in recent years. This is in contrast to the 1979 and 1981 Delphi forecasts that indicated the price of a gallon of gasoline in 1990 would be $4.29 and $4.11 respectively (adjusted to 1990 consumer price index). The 1987 Delphi IV forecast for unleaded regular in 1990 was $1.37 (1990 dollars). The Automobile Club of America's estimate for unleaded regular in 1990 was $1.38.

Strategic consideration

The technology panelists forecast moderate fuel price increases for the next decade. The fact that prices are anticipated to increase as much as they are is likely related to the uncertainty of future taxes on gasoline as a part of the federal deficit reduction effort. Many other factors influence the price and availability of gasoline:

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

Continued stability in fuel prices will allow orderly development of future vehicle programs and components. It is prudent, however, to remember the lessons of the 1970s and consider alternative plans in the event of a major perturbation in any of the factors that can influence the cost or availability of gasoline.

TECH-2 What do you expect CAFE (Corporate Average Fuel Economy) standards for passenger cars and light trucks and vans will be in MYs 1998 and 2003?

Vehicle Type	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Passenger cars	27.5 mpg	30	32	29/30	32/34
Light trucks and vans	20.2 mpg	23	25	22/23	24/26

* Source: United States Department of Transportation, Automotive Fuel Economy Program.

Selected edited comments

- By 2003, CAFE definition will probably change with increased alcohol, electric and hybrid vehicles.
- I believe the government will realize that an increase greater than above would be too difficult to obtain. The public does not want a return to underpowered vehicles.
- Increased CAFE will be driven by customer demand. Rising fuel prices, not government mandates, will increase small car and truck demand.
- It is late in the engineering process for the government to make changes to the 1998 passenger car CAFE. Also, Congress is busy with health care and NAFTA, and should not look at CAFE until the fall of 1994 at the earliest. So only a minor change from current 27.5 mpg is anticipated.
- Standards will be driven by costs, technical limits and drop off in demands/use because of new energy sources.
- The market will not accept higher CAFE when gasoline is so cheap.
- The need for CAFE could go away if government modifies strategies so customers pull manufacturers to increase economy.
- There is minimal opportunity for increases in light truck CAFE.
- This assumes a minimal impact of emissions regulations. Without price increases or regulations, improvements will likely go to performance vs. fuel economy.

Discussion

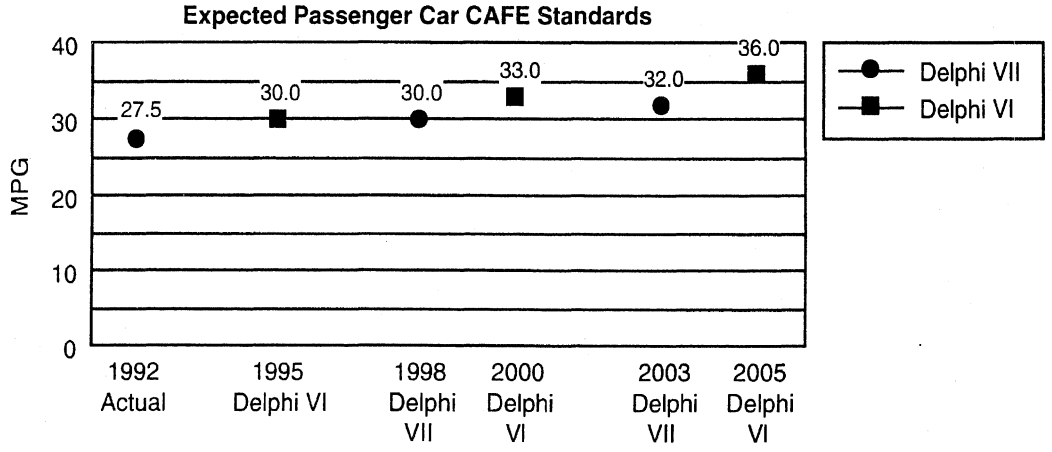
CAFE standards are expected to increase approximately 20 percent in the next decade for both passenger cars and light trucks and vans. This is in contrast to stable passenger car CAFE standards of the past four years, and an increase of only 5.8 percent in the last 10 years.

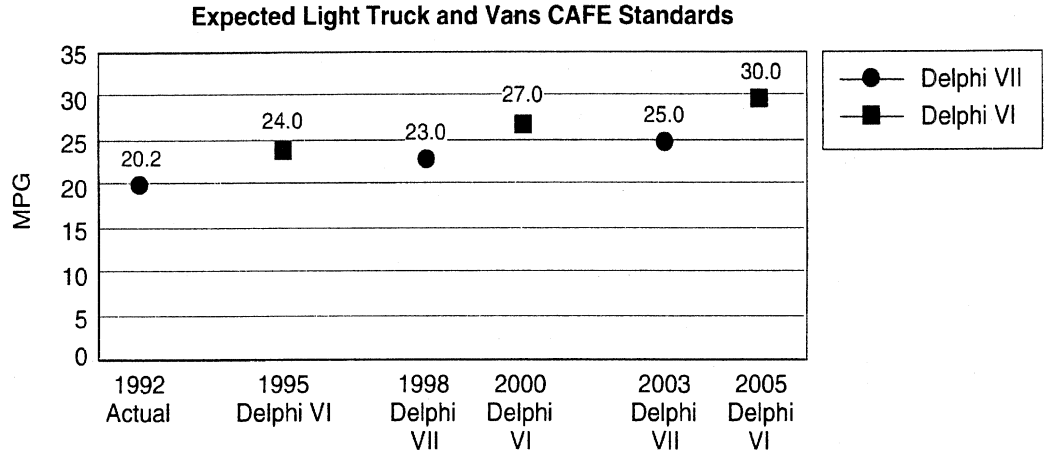
Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI. Those results are compared with the current study in the charts below.





The above charts indicate that the 1994 Delphi VII panelists expect the CAFE standards for both passenger cars and trucks to be somewhat lower than was forecast in the 1992 Delphi VI survey.

Strategic considerations

The forecast for increased CAFE standards will present a major challenge to manufacturers that build primarily full-sized vehicles, considering the forecast fuel prices from the previous question. With relatively low fuel prices, the demand for large vehicles remains high and should continue in the future. It is probable that these forecast standards will force restricted sales of the largest vehicles sold by some manufacturers. Since the fuel economy of a given size and weight vehicle is similar between manufacturers, the net effect is that manufacturers that sell proportionately more large vehicles will be forced to control model mix and vehicle size, whereas those manufacturers that sell predominately small vehicles will not be impacted.

TECH-3 What passenger car CAFE standards can the three traditional domestic manufacturers and other full-line vehicle importers reach, with reasonable effort, in 1998 and 2003? (Reasonable effort means utilizing practical technology, while avoiding substantial reduction in passenger and luggage space and excessive costs for manufacturers and suppliers.)

Manufacturer	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Traditional domestic	27.0 mpg	29	32	29/30	30/33
Japanese - foreign and domestic	32.7 mpg	34	35	33/35	34/38
European - foreign and domestic	24.3 mpg	27	30	26/28	28/31

* **Source:** United States Department of Transportation, Automotive Fuel Economy Program.

Selected edited comments

- As Japanese car fleets become larger (size of car) their fleet average might decline if the market continues to purchase slightly larger size vehicles.
- Emissions will have a grave effect.
- European vehicle manufacturers will be forced to catch up.
- Japanese could be lower if they continue to be driven upmarket by strength of yen.
- Other than traditional domestic, larger cars are not available from the other markets, and people still want large cars and engines.
- The traditional domestic mix of all sized vehicles presents a disadvantage in this category.
- These numbers are very sensitive to product mix. Traditional domestic, with a larger big car population, will not realize the same gains as the foreign (Japanese) cars given the same technological advances.

Discussion

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

CAFE/Manufacturer	1992	1998	2003
CAFE requirement	27.5	30	32
Traditional domestic	27.0	29	32
Japanese-foreign & domestic	32.7	34	35
European-foreign & domestic	24.3	27	30

Attainable CAFE levels are forecast to be as follows for the years 1998 and 2003:

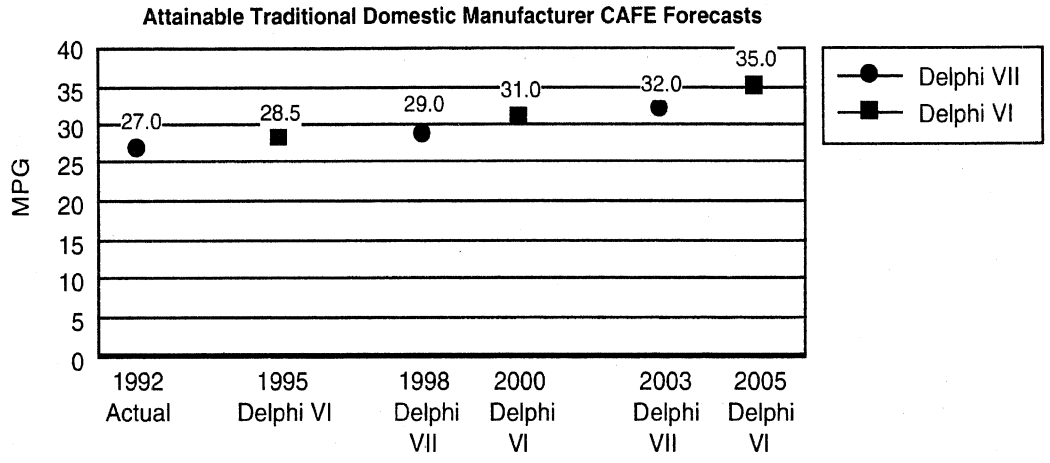
Traditional domestic.....below or at the CAFE standard
Japanese- foreign and domestic.....above the standard
European- foreign and domestic.....below the standard

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement on this issue.

Trend from previous Delphi surveys

This question was asked for the first time in the 1992 Delphi VI survey. The numbers are comparable for domestic manufacturers, but the full-line foreign vehicle importers from all countries were lumped together in the 1992 Delphi VI survey.



The expectations for future attainable CAFE are very similar between the 1992 Delphi VI and the 1994 Delphi VII surveys for the traditional domestic manufacturers.

Strategic considerations

The attainable level for the traditional domestic manufacturers falls on, or very near, the required standard for the period under consideration. The attainable level for the Japanese and European manufacturers falls significantly above and below, respectively, the forecasted required standard. This places the Japanese at a significant advantage with regard to flexibility of volume mix between large and small cars. This is particularly significant since larger cars are generally more profitable than smaller cars. This trend may result in some Japanese manufacturers continuing their move to upscale vehicles. At the same time, the domestic manufacturers will be forced to hold current model mix at best. European manufacturers will be forced to manufacture smaller vehicles or drop V-12 and large V-8s, initiate other design changes, or pay a price penalty on their larger vehicles.

Considering the recent announcement of the Big Three domestic manufacturers and the federal government to pursue development of clean, super-efficient cars, please respond to the following questions (TECH-4 - TECH -8):

TECH-4 What will be the likely maximum fuel economy mpg (EPA test procedures) in production family size (5-passenger) cars in 2010 and 2020? Assume price, safety, convenience, range, performance, etc. on parity with today's vehicles.

Year	Median Response	Interquartile Range
2010	37.5 mpg	35/45 mpg
2020	45 mpg	40/60 mpg

Selected edited comments

- As average mpg increases, each additional increment results in a smaller overall effect. (i.e., 15-30 is a 100 percent improvement. 65-80 is 23 (percent).
- Fuel cells or hybrids are the best bet.
- If successful, there should be no need for mandated fuel economy numbers.
- The CAFE crystal ball remains very unclear. Legislation and technical developments will interact to influence the outcome.
- There is little hope that an invention will solve this problem. The key is making what we already know affordable.

Discussion

Panelists forecast fuel economy of 45 mpg would be possible for an advanced technology five-passenger car for the year 2020, far short of the stated goal of 87 mpg.

Manufacturer/supplier comparisons

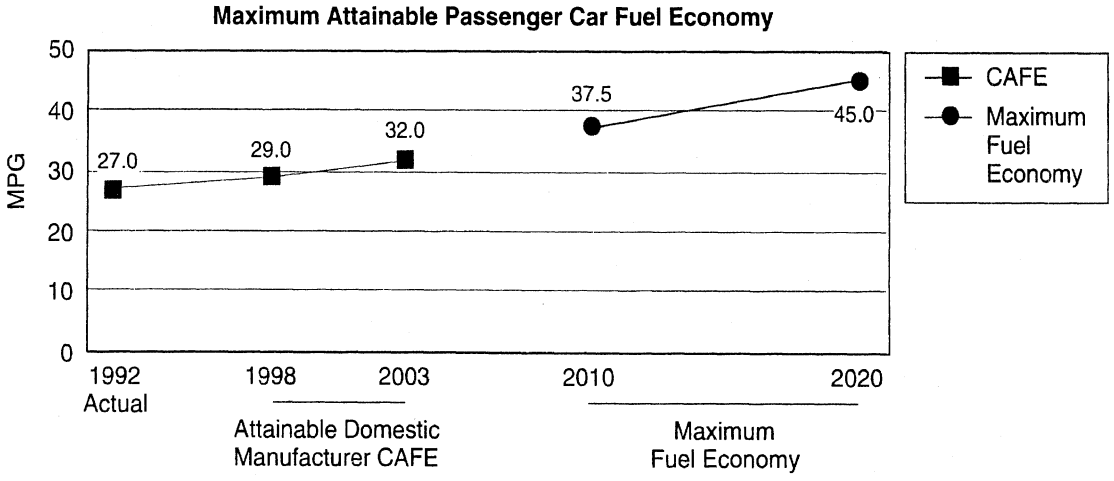
Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Strategic considerations

Responses for this question are compared to the estimates of attainable fuel economy from TECH-3 in the graph below.



A midsized car today with moderate performance has EPA fuel economy quite close to the CAFE average for the domestic manufacturers. Consequently, the conclusion from the above graph is that there is expected to be some acceleration in attainable fuel economy as a result of the cooperative effort between the Big 3 domestic manufacturers and the federal government. The forecast fuel economy improvement from 1992-2003 is approximately 1.7 percent per year, whereas from 2003-2020 it is forecast to increase at an average rate of 2.4 percent per year. As

noted in the comments, the gains will not be a result of a single invention or a few inventions, but rather a compilation of numerous incremental improvements.

Attainment of the above levels of fuel economy would have a significant impact on the amount of petroleum consumed by passenger cars in the United States over a period of time. However, the efficiency of the existing fleet would increase at a low rate even with a substantial increase in fuel economy in any given year's new products. It must also be kept in mind that, as fuel economy is improved, the value of this improvement decreases at the margin. For example, consider a car driven 10,000 miles annually using fuel priced at $1.50 per gallon. If fuel economy were improved from 10 to 20 mpg, the savings is $750 per year. If fuel economy is increased from 30 to 40 mpg, the annual savings is only $125.

Considering the recent announcement of the Big Three domestic manufacturers and the federal government to pursue development of clean, super-efficient cars, please respond to the following question:

TECH-5 Can 87 mpg be achieved in family size (5-passenger) cars?

Panelists Response	Median Response	Interquartile Range
Yes: 28%	By year: 2025	By year: 2015/2035
No: 72%	n/a	n/a

Selected edited comments

- 87 mpg may be achieved if the cost, performance and utility of five-passenger automobiles is compromised. 87 mpg probably will not be achieved with today's characteristics.
- Alternate (replenishable) clean fuels will be a better solution.
- Designing, developing and manufacturing a high fuel economy vehicle that is affordable and meets the customers' needs will be a much greater challenge than defining the technology required to meet high fuel economy targets.
- If the President believes that 87 mpg can be achieved, he did inhale.
- It can't be achieved in affordable vehicles.
- It will be very expensive.
- It will cost a bundle. Even $5 per gallon gasoline has not provided enough push to achieve this ($5 per gallon in Italy today).
- No one in the United States will buy it. Performance and parity with today's vehicles will be poor.
- No, unless major advances in fiber reinforced composites are made on an application or cost basis.
- Not unless cost effective fuel cells can be developed. Since it requires invention success, it is hard to predict.
- Productionizing will be a much greater challenge than just constrained design enablers. I believe the National Labs linkup can achieve the latter. However, much learning will be needed to productionize for cost/volume aerospace technology for $25 million toilets and $15,000 coffee makers.
- There is not enough energy in a gallon of hydrocarbon-based fuel.

Discussion

The vast majority of panelists responded that the goal of 87 mpg is not attainable in the foreseeable future in a family-sized car.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

Less than one third of panelists forecast that 87 mpg will be attainable by 2025. This is consistent with TECH-4, where it was found that the median estimate of fuel economy attainable by 2020 was only 45 mpg, well below the goal of 87 mpg. On the other hand, new inventions or major breakthroughs in technology cannot be readily forecast. The estimates presented are based on extrapolations of the current rate of technology growth. With a commitment to new thinking and the focusing of major new resources on the issue, we should be prepared for surprises. Still, laws of physics being what they are, the goal of 87 mpg is a formidable challenge. One must keep in mind that the demonstration of the technical feasibility of an 87 mpg car is just one small step for mankind. The next giant step to commercialization is extraordinarily difficult.

Considering the recent announcement of the Big Three domestic manufacturers and the federal government to pursue development of clean, super-efficient cars, please respond to the following question:

TECH-6 What technologies will make the greatest contribution to the dramatic improvement in fuel economy and emissions control requirements. Please be as specific as possible.

Summary of Responses	Responses
Engine Improvements	**25%**
Engine efficiency increases	6
Engine control strategies	3
Powertrain efficiency	3
Boosted small engines	2
Combustion control systems	2
Direct acting valve control without inlet throttling; Direct injection; Engine internal airflow; Engine off at idle; Engine temperature management; Fuel burn technology; Two-stroke engines; Valves—individual, adaptive control; Variable displacement; Variable valve timing—electronic control, infinitely variable	1% each
Weight Reduction	**25%**
Material development—low mass, lower cost	18
Weight reduction	7
Vehicle System Improvements	**8%**
Regenerative braking	2
Aerodynamics; Catalyst—new; EV technology; Flywheel technology; Solar regeneration for heating and cooling	1% each
Non-Spark Ignition Engine	**7%**
Fuel cells	3
New engine other than internal combustion; Hybrid electric vehicles; Fuel cell hybrids; Diesels—light truck	1% each
Electronics	**6%**
Electronic controls	2%
Computer power—capacity and speed; Exhaust gas sensors (not O_2); Fly-by-wire; Sensors for engine operation—individual cylinder combustion	1% each
Transmission	**4%**
Transmission	2
Transmission—electronic control	2
Miscellaneous	**9%**
Fuel developments	2%
Batteries for electric vehicles; Compressed natural gas; Energy storage systems for hybrids; Knowledge of cost effective design and manufacturing; Mind set change in corporate leaders; Reduced cycle time—incorporate new technology; Systems approach to vehicles and powertrain	1% each

Discussion

Panelists expect that engine improvements and weight reduction will make the greatest contributions to fuel economy and emission control in the foreseeable future.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked on a previous Delphi survey.

Strategic considerations

As stated in previous questions, large increases in fuel economy will come about not through a single "silver bullet," but through the incremental improvements in many areas. The responses to this question enumerate the many areas that are known today. Almost certainly in the near future there will be inventions, developments or breakthroughs that can be added to this list. The largest number of responses to this question were in the areas of engine improvement and weight reduction. The potential benefit from various sources in the next decade is addressed in TECH-9.

Considering the recent announcement of the Big Three domestic manufacturers and the federal government to pursue development of clean, super-efficient cars, please respond to the following question:

TECH-7 What are the three most significant barriers to transferring defense industries to commercial markets?

Summary of Responses	Responses
Cost and Investment Considerations	**29%**
Cost considerations in design	22%
Investment—tooling, facilities, infrastructure	6
Cost structure in the defense industry	1
High Volume Manufacturing Requirements	**23%**
Process technology and systems for high volume production	9%
Lack of useful knowledge and technologies	6
Cycle time in production—timing requirements	3
Developing manufacturing processes for the technology; Infrastructure requirements; Resources required to produce; Separation of research and development from production; Volume manufacturing variation	1% each
Culture	**14%**
Fundamental bureaucratic inefficiency	4%
Profit objectives are different	2
Willingness to take risk	2
Defense contractors culture must change to reduce waste; Government input; Industry and government bureaucratic behavior; Neither has a clue about the others business; Politics; Trust	1% each
Integration of Organizations and People	**8%**
Communication between the two groups; Coordinating the participants; Engineering processes (specifications, verifications); "Not-invented-here" syndrome; Openness of automotive labs and industry; People; Skills in industry; Understanding how to work with the automotive industry	1% each
Customer Focused Products	**8%**
Lack of customer focused engineered products that provide value	5%
Defense industry must catch up in strange markets; Making management aware of commercial needs; Selling existing technology as opposed to developing for needs	1% each
Supplier Interaction	**2%**
Impact on current suppliers; Suppliers expect big piles of money upfront	1% each
Miscellaneous	**10%**
Legal ramifications of commercial products	3%
Reliability of design—work once vs. long term durability	2
Commercial markets are already maxed out; Industry does not need the extra capacity; Public vs. private funding; Quality requirements; Safety	1% each

Discussion

Panelists note many areas of potential difficulty in integrating government and industry into a cohesive group focused on producing a high-volume product for the customer while providing reasonable profit for the manufacturer. The three general areas most frequently mentioned are cost and investment consideration, understanding high volume manufacturing requirements and cultural differences. These are significant barriers to be addressed in the pursuit of improved vehicles and our transportation system. They strongly suggest a true partnership between government and industry is desirable if we are to maximize customer value.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

New thinking and a new spirit of cooperation must be developed in order to take advantage of the full capabilities of both the government and industry. This process is expected to be difficult at first, considering the comments of the panelists. Visionary leadership will be required to produce the maximum results.

Considering the recent announcement of the Big Three domestic manufacturers and the federal government to pursue development of clean, super-efficient cars, please respond to the following question:

TECH-8 Will this government/industry cooperation bring more realistic regulatory goals and timelines or will it set unrealistic expectations? Please comment.

Government/industry cooperation will bring:	Number of responses
More realistic goals and timeliness	21
Do not know or unclear	9
Unrealistic expectations	11

More Realistic Goals and Timeliness

- Close cooperation will lead to more realistic regulatory goals and will provide a better understanding of technical and market constraints.
- Cooperation is somewhat realistic long term, but the time frame will be too fast. There are many cultural differences.
- Cooperation should bring more realistic goals. Government requirements are now seen to increase costs and cut jobs, so cost/benefit tradeoffs can sometimes be made.
- Cooperation will probably help. Engineers from outside the industry will come to much the same conclusions. "Facts are facts," and government might listen to them.
- Expectations will hopefully be more realistic because of increased dialog.
- Government has never been timely on anything. Government is most adept at overspending and hiding costs from taxpayers. Regulatory goals may be somewhat improved. At least government will be somewhat less of an automotive industry antagonist.
- If handled appropriately, it could reduce the need for regulatory intervention and let the true marketplace take over.
- If there is true cooperation, then goals and timeliness will be realistic.
- It may help regulation or those who advise to better appreciate balance and trade-offs.
- It should help convince government that their goals are not always realistic.
- It will bring more realistic timetables and goals because of enhanced credibility with national lab participation. Cooperation should address process as well as product.
- It will get better.
- Optimistically, it could bring realism to goals.
- Priorities will be more realistic and better balanced with other priorities as both sides better understand the other.
- Short term, it will set unrealistic expectations. It will be successful long term.
- The objective should be realistic goals and achievable accomplishments.
- The process will establish more realistic goals through more mutual trust and understanding.
- There should be more cooperation, but do not trust government.
- There will be more realism as both sides begin to understand the others' limitations and goals.
- There will be more realistic regulatory goals, but goals should be higher if there is cooperation among all parties.

Do not Know or Unclear

- A change in administration may be the biggest unknown.
- Government/industry cooperation could be very beneficial if it can be tempered by an adherence to first principles. If its primary focus is political posturing and public relations fodder, we're all in trouble.
- I foresee longer term frustration with the inability to "immediately" implement change.
- I hope the latter does not materialize. It is unrealistic to regulate or set timetables on invention or creativity.
- It is not clear at this time. If health care is an example, we are in trouble.
- Much depends on whether the government believes the cost figures.
- Progress reports and reality checks should be held periodically as things evolve to better define regulatory goals before they are locked in.
- There are no unrealistic expectations, only the means at that time to limit our progress.
- Time will tell.

Unrealistic expectations

- Cooperation will probably lead to less realistic goals.
- Cooperation will probably lead to unrealistic expectations like Freon changes.
- Every new invention will drive new unrealistic expectation and regulations. Government does not understand "commercially viable." Read Vice President Gore's book; he is out to kill the internal combustion engine regardless of the facts.
- More regulation will result as government tries to connect cooperation and support to achieving social goals.
- No realistic goals will come of increased cooperation.
- Once the government starts to be part of the industry they will want to control the automotive industry.
- Politics will prevail.
- There will be no useful benefit for some time until government begins to understand the basics of business (design, manufacture, and sell at a reasonable cost a product that appeals to customers to make a profit. Government earns money through taxation, not value-added.)
- There will be unrealistic expectations initially until effective working relationships are established.
- This did nothing to solve the competing agency, department and branch government problems.

Discussion/Strategic considerations

Panelists' responses indicate by a ratio of almost 2:1 that more realistic regulatory goals and timeliness would be a result of the industry/government joint effort. Significant skepticism is indicated in many of the responses, however. This joint effort provides an opportunity for both government and industry to draw closer together in setting goals and priorities that are beneficial to the nation as a whole. It also provides the opportunity to build a mutual trust which has been heretofore minimal at best.

TECH-9 What percentage of overall CAFE improvement will come from each of the following sources:

Sources	Median Response		Interquartile Range	
	1998	2003	1998	2003
Engine efficiency	21%	20%	15/25%	15/25%
Weight reduction, without downsizing	20	20	15/25	15/25
Downsizing	10	11	8/10	10/15
Transmission efficiency	10	10	8/10	10/12
Aerodynamics	5	5	5/6	5/7
Reduced performance	5	5	0/6	0/5
Reduced tire rolling resistance	5	5	3/5	5/5
Accessory drives	5	5	4/5	4/5
Regenerative braking	0	0	0/0	0/2
Supercharger with engine downsizing	0	1	0/5	0/5
Turbocharger with engine downsizing	0	0	0/3	0/5
Total	81%	82%		

Other responses include:

Alternate energy–1998:10 percent; 2003: 30 percent.

Drive-by-wire– 1998: 5 percent; 2003: 15 percent.

Electric power consumption management– 1998: 6 percent; 2003: 12 percent.

Improved powertrain systems, Engine specific power–1998: 20 percent; 2003: 5 percent.

Improved powertrain isolation et al. so engine can run at lower BSFC operating points–1998: 10 percent; 2003: 18 percent.

(**Editors' note:** Isolation could mean engine mounting allowing low speed operation, or use of a hybrid or CVT transmission).

Selected edited comments

- Any reduction in performance won't be tolerated.
- Engine efficiencies include provision for the two-stroke engine entering the market.
- Higher voltage electrical systems will substantially reduce weight and make electrically variable drive more cost effective and realistic.
- Re: Engine efficiency will contribute 20 percent in 1998 and 10 percent in 2003. This includes revised transmission shift schedules so engine can be run at better BSFC points.
- Reduced performance, reduced tire rolling resistance and regenerative braking will comprise 25 percent of this overall improvement.
- The potential of supercharged smaller engines is substantial. This will come into practice as completely new engines are laid down and tooled.
- This will be driven by lead time available after new standards become law.
- We will see an increase in low rolling resistance tires and away from the high speed handling tires.
- We will see most of the powertrain effort up to 1998 focused on meeting new emission laws.

Discussion

The largest sources of fuel economy improvement over the next 10 years are expected to be in the area of weight reduction, engine efficiency, transmission efficiency and downsizing.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement with the exception of the areas noted in the following table.

Sources	1998		2003	
	Manufacturers	Suppliers	Manufacturers	Suppliers
Supercharger with engine downsizing	0%	3%	0%	3%
Turbocharger with engine downsizing	—	—	0	1

Trend from previous Delphi surveys

As in previous Delphi forecasts, improved engine efficiency and weight reduction continue to be the most significant areas of anticipated improvement in fuel economy. The potential improvement due to downsizing has been reduced since the last survey.

Source of improvement	Forecast for 2000		Forecast for 2003
	1989 Delphi V	1992 Delphi VI	1994 Delphi VII
Engine efficiency	25%	15%	20%
Weight reduction	20	20	20
Downsizing	5	20	11
Transmission efficiency	—	10	10

Strategic consideration

The reduced potential attributed to downsizing compared to previous Delphis may be a result of the continued demand for larger cars in the marketplace. Some earlier attempts at downsizing were rejected in the marketplace with significant financial consequences. This may place added pressure on vehicle costs as weight reduction is pursued through the use of lightweight, more costly materials. The shift in material usage and the sources of efficiency improvements in engines and transmissions is addressed in later questions.

Most sources of fuel economy improvement will come about only with significant capital expenditures and potential increases in component piece cost as a result of materials changes, unless some significant advances are made in design and production technologies. An opportunity is present for suppliers to develop and bring forward new technology or advances to provide weight reduction or fuel efficiency improvements.

TECH-10 How much weight reduction and downsizing would be required to meet a passenger car CAFE standard of 30 and 35 mpg by 2003? Please use the optimal combination.

Effects of Increased CAFE standards	Median Response		Interquartile Range	
	30 mpg	35 mpg	30 mpg	35 mpg
Percentage weight reduction	15%	20%	10/20%	15/30%
Percentage downsizing	10	15	5/20	10/30

Selected edited comments

- Americans will still want space.
- I do not feel downsizing will be a viable option.
- In general there cannot be significant weight reduction without downsizing.
- It is all tradeoffs. However, market forces limit the amount of performance reduction or cost increase that can be tolerated without resorting to mass/size reduction.
- This type of reduction would allow for a sympathetic reaction in engine size and torque converter gain/transmission.

Discussion

Substantial weight reduction and downsizing would be required to meet CAFE standards of either 30 or 35 mpg.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement on this issue.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey regarding fuel economy targets of 35 and 40 mpg for 2000 versus targets of 30 and 35 mpg in 2003 in the present study. Comparison estimates are summarized below.

Effects of Increased CAFE standards	1992 Delphi VI for 2000		1994 Delphi VII for 2003	
	35 mpg	40 mpg	30 mpg	35 mpg
Percent weight reduction	20%	30%	15%	20%
Percent downsizing	20	25	10	15

To meet 35 mpg, forecasts for weight reduction are the same at 20 percent between the 1992 Delphi VI and the 1994 Delphi VII surveys, whereas the forecast for downsizing has dropped from 20 percent to 15 percent for the present study.

Strategic considerations

The results of this question are in line with the previous question regarding the forecast for less downsizing than expected, based on the previous Delphi survey. This again reflects market forces for current or forecasted fuel prices. It also reinforces the fact that attaining significantly higher CAFE targets will be very difficult without using the effective parameter of downsizing. Attaining CAFE standards higher than those forecast in this study will be done only with major disruption of natural market forces.

The term "percent downsizing" is not absolute, as the units of measurement are intentionally not specified. Potential units of measure could be total vehicle volume, EPA volume, plan view area or some other measure. Since these units of measure are so dependent on vehicle type, usage and styling, the units were omitted and the results give only a directional measure.

TECH-11 What percentage of North American-produced passenger cars and light trucks (including fleets) will use each of the following alternative energy sources in MYs 1998 and 2003?

Alternative Fuels	Est. 1992*	Passenger Cars				Light Trucks			
		Median Response		Interquartile Range		Median Response		Interquartile Range	
		1998	2003	1998	2003	1998	2003	1998	2003
Alcohol or Alcohol/gasoline (>10% alcohol; includes flex fuel or variable fuel)	0.5%	1.0%	5.0%	.7/2%	1/10%	1.0%	2.0%	0.5/2%	1/6%
Diesel	1.2	1.0	2.0	.5/2	1/3	3.0	5.0	2/5	4/10
Electric	0.0	0.2	1.0	0/1	.5/2	0.0	0.3	0/0.5	0/1
Electric/gasoline hybrid	0.0	0.0	1.0	0/1	.1/2	0.0	0.5	0/0.5	0/1
Natural Gas	0.0	0.5	2.0	0/1	.5/5	1.0	2.0	0.5/2	1/7
Propane	0.0	0.1	0.5	0/1	0/2	0.1	1.0	0/1	0/3

***Source:** Various OSAT estimates.

Other responses include:
Enhanced gasoline: 1998 = 85.9 percent; 2003 = 70.9 percent for passenger cars and 1998 = 77.5 percent; 2003 = 57.5 percent for light trucks.

Selected edited comments

- Alcohol/gas will not make significant inroads without an external "economics modifier" because there is currently no incentive.
- Diesel usage depends on EPA and oil prices. It offers significant fuel consumption advantages. The electric hybrid will only happen beyond 1 percent by politics.
- Electrics will remain niche only except where driven by legislation or some yet to be consummated initiatives.
- I believe the demand for alcohol/gasoline-powered vehicles will be led by the Latin American and South American markets.
- Most NVG vehicles will be bifueled with gasoline. Diesels in light duty trucks will for the most part be direct injection.

Discussion

Energy sources other than gasoline are forecast to see limited application in the next decade, but are significant in terms of vehicle numbers.

Manufacturer/supplier comparison

Responses for manufacturers and suppliers were very similar with the exception of the areas included in the following table.

Alternative Fuels	Manufacturers		Suppliers	
	1998	2003	1998	2003
Passenger cars				
Alcohol or alcohol/gasoline (>10% alcohol; includes flex fuel or variable fuel)	—	3%	—	5%
Light-duty trucks				
Alcohol or alcohol/gasoline (>10% alcohol; includes flex fuel or variable fuel)	—	2%	—	5%
Diesel	3	—	5	—
Electric	—	0.2	—	1

Comparison of forecast: MKT-34

Diesel and light trucks are not addressed in the marketing survey. Passenger car results between the two surveys are in agreement with the exception of the areas noted in the table below.

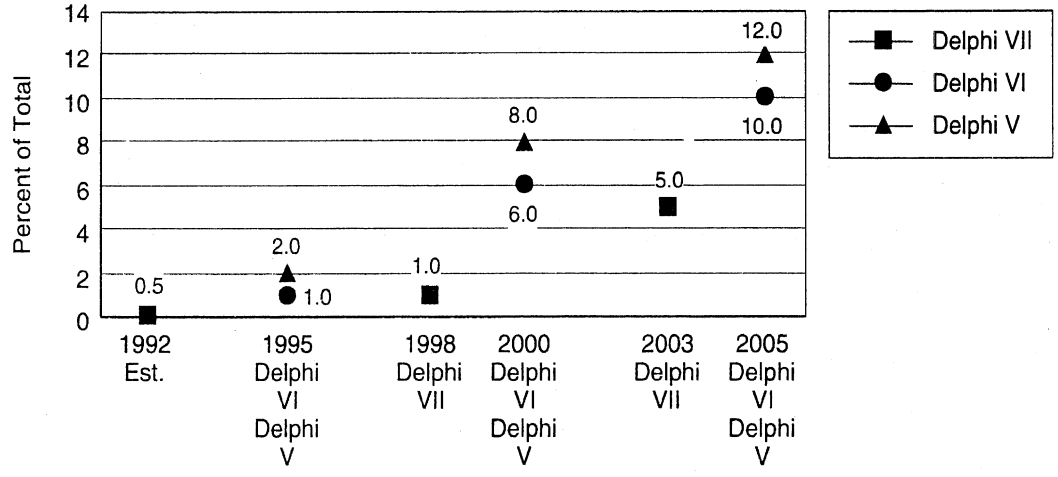
Alternate Fuels	Est. 1992	Median Response 2003	
		TECH	MKT
Alcohol or alcohol/gasoline	0.5%	5%	3%
Natural gas	0	2	1

*Source: Various OSAT estimates.

Trend from previous Delphi surveys

This question was previously asked for passenger cars only, and then only for alcohol or alcohol/gasoline, natural gas and propane. Natural gas results were very similar between this and the previous survey. The results for alcohol or alcohol/gasoline and propane between this and the previous survey are summarized in the following graphs.

Alcohol or Alcohol/gasoline Use Forecasts
North American Passenger Car Production



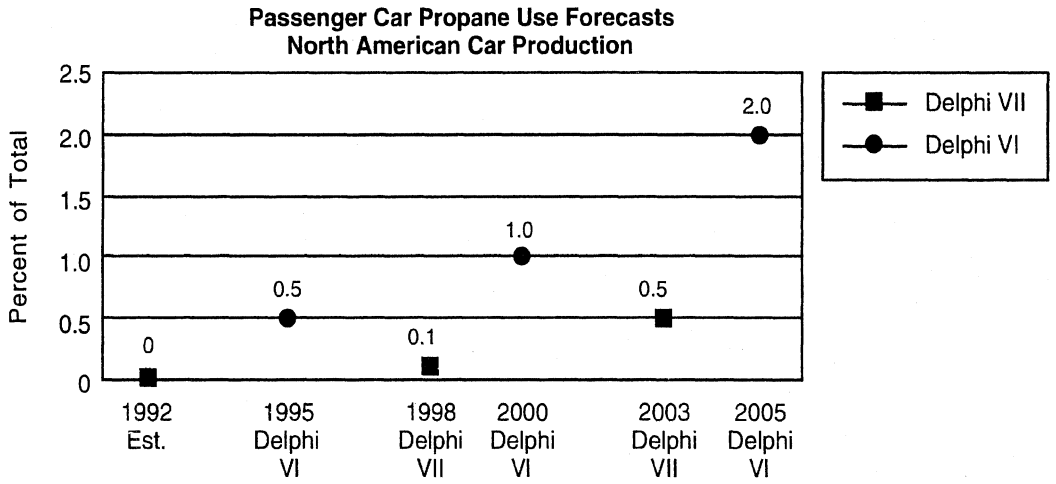
Current panelists forecast a reduced and/or delayed introduction of alcohol or alcohol/gasoline fueled vehicles compared to those responding in the two previous studies.

Ethanol, derived mainly from biomass, was considered by the 1984 Delphi III panelists to be in the low range of probability. This was insightful considering the experience of Brazil's aggressive move towards ethanol-fueled vehicles and the subsequent failure of the sugar cane harvest from which the ethanol was derived. This resulted in the idling of approximately 30 percent of the Brazilian domestic motor vehicle fleet.

Thirty-five percent of the 1987 Delphi IV panelists considered the likelihood of vehicle

utilization of methanol derived from natural gas as very high; 48 percent considered the likelihood as moderate. Methanol derived from coal as a North American produced passenger vehicle fuel source was given a very high likelihood by 33 percent of the 1989 Delphi V panelists and a moderate rating by 36 percent.

In the 1984 Delphi III survey, the following question was asked: "*Assuming no major international dislocation in petroleum supply and/or price, in what year do you expect synthetic or alternative fuel will be produced in significant quantities (1 million barrel/day in the U.S.)?* The median panelist response was 2004 or later, and the low end of the interquartile range was 1995.



Current panelists forecast a delayed and/or reduced usage of propane in passenger cars, as compared to panelists of the 1992 Delphi VI.

Strategic considerations

Other fuels have an advantage to the customer in one or more areas over gasoline. But considering all factors, gasoline is far and away superior to the other alternatives. Diesel is the only alternative that offers superior vehicle range and fuel cost on a dollars-per-mile basis. The disadvantages of diesel to the customer are significant, however, and include performance, cold starting capability, more frequent oil changes, odor and higher initial vehicle purchase price. The greater mass of a diesel engine is a design disadvantage. Exhaust emissions control also presents a significant challenge for the diesel.

The incentives to move away from gasoline are primarily environmental and include reduced emissions of hydrocarbons, carbon monoxide and oxides of nitrogen. The diesel engine also produces less carbon dioxide, as less fuel is used. This is an advantage with regard to the "greenhouse" effect. Electric power has the potential to reduce carbon dioxide emissions, but only if nuclear, wind, hydroelectric or some other non-carbon energy source is used to generate the electricity, or a method is developed to remove carbon dioxide from stationary power plant exhaust.

A further incentive to move away from gasoline as an energy source is the potential to reduce the balance of payments of the United States as a result of reducing petroleum imports. A country that imports a major portion of its energy from other countries is, in effect, captive to the political and economic conditions of the exporting countries. This is a lesson that the United States learned painfully in the 1970s.

Since the customers' needs are best met today by gasoline, the demand for gasoline will only decrease if conditions are changed through legislation or world perturbations in the availability or price of petroleum.

Legislation that forces the consumer to choose from alternatives that are not in his best personal short-term interest will be viewed critically by the consumer, who also happens to be a voter. Legislators make radical changes in this area at their own political peril. If the best long-term interest of the consumer is the basis for a change; the communication of this long-term interest must be made abundantly clear to the consumer.

Finally, the experiences of Brazil with ethanol suggest that alternatives that look good today may have hidden pitfalls in the long run.

This matter requires the greatest possible study and analysis and a good bit of systems thinking to assure that the proper solutions are implemented.

TECH-12 What are the major obstacles to the widespread (> 25% marketshare) use of alternative energy sources for passenger vehicles, where 1 = major and 5 = minor?

Energy Source	Infrastructure	Lifetime Vehicle Cost	Vehicle Range	Convenience	Safety
Alcohol or alcohol/gasoline	2.9	3.6	3.5	4.2	2.1
Electric	1.5	1.2	2.1	3.9	2.9
Electric/gasoline hybrid	1.7	3.1	3.1	4.0	1.8
Natural gas	3.2	2.5	2.4	2.9	2.3
Propane	3.1	2.9	2.6	2.8	2.9

Other responses include (followed by ranking):

Bi-fuel natural gas vehicles - gasoline—Infrastructure: 3.0; Lifetime Vehicle Cost: 4.0; Vehicle Range: 5.0; Convenience: 5.0; Safety: 5.0.

Diesel—Infrastructure: 4.0; Lifetime Vehicle Cost: 4.0; Vehicle Range: 5.0; Convenience: 4.0; Safety: 5.0.

Cleaner gasoline—Infrastructure: 3.0; Lifetime Vehicle Cost: 4.0; Vehicle Range: 5.0; Convenience: 5.0; Safety: 5.0.

Hydrogen—Infrastructure: 1.0; Lifetime Vehicle Cost: 1.0; Vehicle Range: 3.0; Convenience: 2.0; Safety: 1.0.

Hydrogen—Infrastructure: 1.0; Lifetime Vehicle Cost: 3.0; Vehicle Range: 1.0; Convenience: 1.0; Safety: 2.0.

Reformulated Gasoline—Infrastructure: 5.0; Lifetime Vehicle Cost: 5.0; Vehicle Range: 5.0; Convenience: 5.0; Safety: 5.0.

Selected edited comments

- As Yogi Berra might say about alternative fuels: "They won't be popular until they're popular."
- Customer acceptance/perception of the downsides of alcohol or alcohol/gasoline exceeds reality. This is the major obstacle.
- Electric cars and weight are inversely related. Electric cars just shift the pollution basis.
- Performance is a major obstacle to using electric and electric/gasoline hybrid vehicles.
- The battery is still a major technical and infrastructure problem for the electric vehicle.
- This differs for fleets and individually owned/leased autos. Attention should be addressed to cleaner burning gasolines. The oil industry is making advances in that arena.
- Vehicle range and convenience are the major obstacles most difficult to overcome.

Discussion

It is apparent that the panelists feel all alternative energy sources have some significant obstacles to widespread use. Assuming that all obstacles listed are of equal importance, and that these are the only obstacles, a ranking of the various energy sources is shown below using the average of obstacle ratings.

Energy Source	Rating	Average Obstacle Rating
Alcohol or Alcohol/gasoline	1	3.3
Propane	2	2.9
Electric/Gasoline hybrid	3	2.8
Natural Gas	4	2.7
Electric	5	2.3

Other factors, including environmental benefit, must be considered to fully evaluate the various energy sources for potential use. The global environmental benefit of electric vehicles may be in question, for example. Yet, the benefit to a local area such as Los Angeles may be significant if electricity is generated outside the Los Angeles basin. A comprehensive analysis of the pros and cons of each energy source is beyond the scope of this study. The results of this study could be used to advantage in such an analysis, however.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement with the exception of the results shown in the following table.

Energy Source	Lifetime Vehicle Cost	
	Manufacturers	Suppliers
Alcohol or Alcohol/gasoline	3.3	3.9
Electric/gasoline hybrid	1.4	2.0

Trend from previous Delphi surveys

This is the first time that this question has appeared in a Delphi survey.

Strategic considerations

The strategic considerations in any significant switch to an alternative energy source could have far-reaching implications from a financial, political and environmental standpoint. A switch away from gasoline could impact significantly the following:

- The balance of payments of the United States
- National security as a result of reduced dependence on petroleum
- Shifts in the job market in the areas of procurement, refining and distribution of petroleum products–including major regional job relocations required within the United States
- Demand for capital for the alternative energy source and the modification or replacement of the propulsion system
- Increased cost to the consumer for some of the alternative energy sources as well as the new power source
- Potential safety issues and resulting litigation
- A trade-off of environmental issues. (e.g., electric vehicles that reduce air pollution but increase hazardous waste from storage batteries)

The above assumes a significant switch to an alternative energy source. Perhaps the greatest impediment to alternative sources is the market demand for these alternatives and the manufacturer's ability to address all of the alternatives at roughly the same time—a dilution of effort. Customers will continue to buy the vehicle that best meets their needs with respect to life cycle cost, performance and convenience. At the forecast fuel prices, gasoline continues to best meet customer requirements. From a public policy/business/economic perspective, we would hope that major policy decisions be implemented after a true total systems analysis of the issues. If good policy/economics analysis is not used to support policy actions, significant economic and political problems could result.

For the lower percentage of applications, natural gas may be the most economical—particularly in fleets.

TECH-13 What types of batteries will likely be used in electric or hybrid vehicles in MYs 1998 and 2003?

Types of Batteries	Median Response		Interquartile Range	
	1998	2003	1998	2003
Lead-Acid	80%	50%	75/90%	50/69%
Lithium-Aluminum/Iron-Sulfide	0	0	0/0	0/0
Nickel-Hydride	0	10	0/1	2/20
Nickel-Cadmium	5	5	5/10	5/10
Nickel-Iron	0	0	0/4	0/5
Sodium-Sulphur	1	10	0/5	5/20
Lithium polymer	0	5	0/3	0/10
Total	86%	80%		

Other responses include:

Polymer–1998: 1 percent; 2003: 3 percent.

To be discovered–1998: 4 percent; 2003: 50 percent.

Selected edited comments

- Electric cars actually create more pollution than equivalent performance internal combustion vehicles. They just move it somewhere else.
- Electric vehicles are likely to have a combination of different kinds of batteries. One kind is likely to become the dominant replacement for lead-acid but it is not clear which one.
- Electric vehicles make no sense at all despite the situation in California. The laws of nature will eventually solve the electric car problem.
- I do not believe total volumes will be significant. It is too early to predict 2003.
- Lead-acid doesn't meet necessary minimum performance criteria. No other viable alternative currently exists, so a breakthrough cannot be predicted.
- Lead-acid is a near-term solution.
- The electric vehicle effort is in big trouble.
- There are serious safety concerns for sodium-sulphur.
- Unless Ovonics Inc. has a major breakthrough, the electric vehicle effort could be in big trouble.

Discussion

In spite of the serious shortcomings of the lead-acid battery, the panelists forecast that overall this is still the leading EV battery candidate for the next decade. Other candidates posess superior performance and range potential, but all have other drawbacks limiting their potential use. Success in the development of an alternative to the lead-acid battery–or significant improvements in the lead-acid battery–hold the key to the widespread use of electric vehicles, assuming that market forces are allowed to work. Short of a breakthrough in this area, only legislation or significant taxes on gasoline or financial incentives for electric vehicles will effect widespread usage of electric vehicles.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement with the exception of the area noted in the following table.

Types of Batteries	1998	
	Manufacturers	Suppliers
Lithium polymer	0%	5%

Trend from previous Delphi surveys

This is the first time that this question has been asked in the Delphi study.

Strategic considerations

California has provided the regulatory incentive to produce electric vehicles, but as yet economically viable technology does not exist to produce and market a competitive electric vehicle. The cost is prohibitive to develop and tool an electric vehicle that may not be accepted in the marketplace. As a result, cooperative efforts, particularly in the area of battery development, will continue. Widespread usage of electric vehicles is awaiting the success of these efforts. The growing relationship between government and industry could have a profound effect on the near term and probably longer term role of electric vehicles. The greater the sense of ownership on the part of government in the technological and market factors, the greater likelihood reason will prevail. This could lessen the chances that policy makers could err and be blamed for a major policy faux pas.

TECH-14 What is the likelihood of federal legislation mandating or regulating the following automotive features by the year 1998, where 1 = Extremely likely and 5 = Not at all likely? Please identify any other features in the comments section.

Automotive Features	Mean Forecast
Onboard emission control diagnostics	
Passenger car	1.8
Light truck	2.1
Antilock braking systems (ABS)	
Passenger car	2.8
Light truck	2.9
Alternate fuel capability	
Passenger car	2.8
Light truck	3.2
Driver impairment interlocks	
Passenger car	3.7
Light truck	3.9

Selected edited comments

- ABS is likely to grow so rapidly that ABS legislation will not be required.
- An insurance break could substitute for legislation on driver impairment. Drunk driving hasn't surfaced in the current debate about health care and costs. Considerable savings could be obtained; yet the resistance to impingement on individual rights could be great.
- California will lead the way again.
- Industry will provide 100 percent ABS because our customers require it. If a law is passed, it will be after-the-fact documentation. On-board emission control diagnostics regulations are in place now, effective with the 1996 model year.
- Onboard emission control diagnostics (and OBD II) are scheduled for implementation starting in 1995.
- Selective use of driver impairment prevention devices will be most likely to apply to specific individuals by court order.
- There will not be legislation on anti-lock brakes per se, but standards will be written that can only be met with ABS.

Discussion

The panelists view as somewhat likely the probability of legislation in the areas of alternate fuel capability and antilock braking systems (ABS). California will lead the way on alternate fuels. Legislation on ABS may be a mute point, since the industry and market demand are mandating the application of ABS.

Legislation regarding driver impairment interlocks is considered unlikely. This is most likely based on the negative public reaction to seat belt interlocks mandated a number of years ago, and new concerns about individual rights versus the public good. Of course, technology could have a significant impact as well.

Onboard emission control diagnostics for light trucks are considered likely, following the lead of passenger cars which will have this requirement beginning in 1995.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement regarding legislation on alternate fuel capability and driver impairment interlocks. Differences in forecasts for antilock braking systems and onboard emission control diagnostics are summarized below.

Automotive Features	Manufacturers	Suppliers
Antilock braking systems (ABS)		
Passenger car	3.1	2.5
Light truck	3.1	2.7
Onboard emission control diagnostics		
Passenger car	1.5	2.2
Light truck	1.8	2.5

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey but the responses were in a different form, making the results not directly comparable. The 1992 Delphi VI survey response is shown below regarding the likelihood of federal legislation mandating or regulating the following automotive features by 2000.

Automotive Features	Likely	Not likely
Alternate fuel capability	74%	26%
Antilock braking systems (ABS)	54	46
Driver impairment interlocks	22	78

Responses for antilock braking systems and driver impairment interlock systems were similar between the Delphi studies in 1992 and 1994. Legislation on alternate fuel capability is deemed less likely in the present study.

On-board emission control diagnostics for light trucks was not considered in the 1992 Delphi VI study.

Strategic considerations

With the exception of driver impairment interlocks, panelists consider somewhat likely the probability of application of new or increased regulations on the features selected. It would be to the advantage of manufacturers and suppliers to be pro-active in the development of these regulations with regard to technical feasibility, cost impacts and timing. Legislation developed in a joint manner with industry will result in the best, most cost-effective solutions for the nation as a whole.

TECH-15 **Please indicate your view of the trend in U.S. federal regulatory/legislative standards over the short term (1994-1998) and long term (1999 to 2003), where 1 = much more restrictive, 3 = no change, and 5 = much less restrictive. Also, please list any likely new areas of legislative activity.**

Legislative/Regulatory Standards	Mean Rating	
	Short term 1994-1998	Long term 1999-2003
Antitheft		
Passenger car	2.7	2.3
Light truck	2.8	2.4
Fuel economy standards (CAFE)		
Passenger car	1.9	1.5
Light truck	2.0	1.5
Occupant restraint/interior safety		
Passenger car	2.1	1.8
Light truck	2.0	1.8
Product liability		
Passenger car	2.5	2.4
Light truck	2.5	2.4
Vehicle emission standards		
Passenger car	1.9	1.6
Light truck	1.9	1.5
Vehicle integrity/crashworthiness		
Passenger car	2.1	1.8
Light truck	2.1	1.7

Long-term "new area" responses include:
Recyclability: 1.0 (6 responses); ABS: 1.0 (2 responses); Electric Vehicle Safety: 1.0 (1 response); Refueling - vapor recovery and dry seal filler necks: 1.0 (1 response); Recyclability: 2.0 (3 responses).

Short-term "new area" responses include:
ABS: 2.0 (1 response); Recyclability: 2.0 (8 responses).

Selected edited comment

- Safety is a marketing strategy. Legislation will probably not be required. Product liability is the most serious threat to the auto industry.

Discussion

Panelists forecast more restrictive regulations in vehicle emissions, fuel economy, safety, product liability and antitheft, both in the short term and the long term. The most significant changes are expected in fuel economy and vehicle emissions standards.

Manufacturer/supplier comparison

Results for manufacturers and suppliers are in agreement.

Comparison of forecasts: MKT-6 & MAT-5

Materials and marketing panelists are in agreement in all areas with one exception. Marketing panelists rank long-term occupant restraint/interior safety for light trucks at 2.51, which is somewhat less likely than the 1.81 ranking by technology panelists.

Trend from previous Delphi surveys

The rating system for this question is changed from previous forecasts. In previous forecasts, respondents were asked to describe future regulations as more restrictive, same or less restrictive. Results were presented as percent of respondents indicating each of the three choices. In the current forecast, panelists are asked to circle numbers 1-5, where 1 = much more restrictive and 5 = much less restrictive. The results of the two previous forecasts are compared to the current forecast in the following table.

Forecast for time period:	TECH Panel: Percent of Total Respondents							
	1988-1998			1993-2000			1994-1998	1999-2003
Legislative/Regulatory Activity	1989 Delphi V			1992 Delphi VI			1994 Delphi VII	
	More	Same	Less	More	Same	Less	Rank	Rank
Antitheft								
Passenger car	—	—	—	—	—	—	2.68	2.34
Light truck	—	—	—	—	—	—	2.81	2.42
Fuel economy standards (CAFE)								
Passenger car	30%	58%	12%	90%	10%	0%	1.93	1.51
Light truck	4 4	47	9	89	11	1	1.96	1.53
Occupant restraint/ interior safety								
Passenger car	83	17	0	58	41	1	2.09	1.83
Light truck	—	—	—	78	22	0	2.00	1.81
Product Liability								
Passenger car	51	43	6	27	67	6	2.54	2.43
Light truck	—	—	—	30	64	6	2.54	2.43
Vehicle Emission Standards								
Passenger car	76	23	1	65	34	1	1.86	1.60
Light truck	88	11	1	81	19	1	1.86	1.54
Vehicle integrity/ crashworthiness								
Passenger car	85	15	0	55	44	1	2.07	1.78
Light truck	87	12	1	77	22	1	2.07	1.78

As in the previous two forecasts, the current forecast expects increased legislation in all areas under consideration.

It is not possible to directly correlate results with past surveys because of the change in format. It is possible to conclude directionally that the panelists anticipate greater changes in long-term fuel economy regulations than they did in 1989.

Strategic consideration

Although fuel economy is market-driven on an individual vehicle basis, it is not on a corporate average basis. CAFE is primarily driven by the product mix of the manufacturer as opposed to the fuel economy of a given size or body style of the individual vehicles made by that manufacturer. As noted previously, this may force a change in the sizes and styles of vehicles and powertrain offerings made by some manufacturers, primarily European and domestic. This shift in product mix may have a significant impact on the profitability and competitiveness of the affected manufacturers.

Safety is market-driven to a large extent. As a result, many safety features are implemented prior to mandatory legislation.

TECH-16 Please check the response that indicates your view of the trend in government emphasis on cost/benefit analysis in setting standards, where 1 = much more emphasis and 5 = much less emphasis.

Government Emphasis	Mean Rating
Cost/benefit analysis in setting standards	2.7

Selected edited comments

- 1992 election results will overrule reasonableness.
- Cost pressures will demand a more objective approach.
- I think public opinion will have an influence on the government to hold costs in line.
- It does not appear that any such analysis is done at all by the government!!
- It is a little too early to gauge.
- The trouble is that input is generally ignored with government doing their own estimates without understanding system issues.

Discussion

Panelists forecast a slight increase in the use of cost/benefit analysis by the government in the development of standards and regulations.

Manufacturer/supplier comparison

Results for manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

Panelists forecast no significant change in the use of cost/benefit analysis by government in setting standards. How an individual interprets this response is to a large measure dependent on how satisfied the individual is today with the apparent cost/benefit analysis used currently in the setting of standards. The comments would suggest that there is a wide range of opinion on this matter, with the preponderance of feeling being that inadequate cost/benefit analysis is used today.

The final direction of government in this area will have a major impact on corporate profits, the discretionary income available to all citizens, and our effectiveness in meeting public goals.

TECH-17 What do you believe that the U.S. Congress should do, or should not do, to assist the traditional, domestic automotive industry? Consider "automotive industry" to include both vehicle manufacturers and suppliers.

The U.S. Congress Should:	Yes	No	No response
Coordinate legislation, government agencies and other policy activities	91%	8%	1%
Regulate based on technical considerations	68%	27%	5%
Increase gasoline prices	64%	32%	4%
Manage trade, foreign domestic investment	48%	47%	5%

Other single "yes" responses include:

Congress should control imports and develop overall industrial policies

Fair trade; Get the judicial system under control

Increased gas tax, less CAFE; Jaw-Bone/Suggest rather than regulate

It should do what others do to us; turnabout is fair play

Listen/communicate rather than confront

National policy on increasing U.S. automotive competitiveness in product and process

Reform torte liability statutes

Understand cost benefit relationship

Work to develop national requirements, eliminating different requirements by individual states

Work with the auto industry

Selected edited comments

- Congress does not understand technical considerations.
- I do not like regulation of any kind. Let the free market decide what should be done.
- Increase gasoline prices vs. CAFE increase.
- Leave the industry alone now that we've figured out how to handle global competition.
- Monitor balance of trade in critical high dollar commodities and help eliminate one-way roadblocks.
- Only increase gasoline prices to satisfy infrastructure needs.
- Torte liability is a big issue which the industry hasn't addressed with a united front.

Discussion

The majority of panelists respond that the U.S. Congress should assist in coordinating legislation, government, and other policy activities; increasing gasoline prices; and regulating based on technical considerations. Panelists are split with regard to the role of Congress in managed trade.

Manufacturer/supplier comparison

Results for the first two categories are in close agreement. Results for the last two categories are summarized below.

The U.S. Congress should:	Percent of Respondents Answering *YES*	
	Manufacturers	Suppliers
Regulate based on technical considerations	78%	63%
Manage trade, foreign domestic investment	58	42

Manufacturers respond substantially more favorably than suppliers with regard to the involvement of Congress in managing trade and foreign domestic investment, and regulating based on technical considerations. The positive response to manage trade may reflect concern of the manufacturers that trade with may not be considered to be fair between all countries with regard to

total vehicle sales. The manufacturers' strong desire to see regulation based on technical consideration may reflect the difficult standards currently in place for vehicle emission control and the anticipation for significantly higher fuel economy standards. These standards impact the manufacturer more than they do the supplier.

Trend from previous Delphi surveys

In the 1992 Delphi VI survey, this was an open-ended question regarding what the U.S. Congress should or should not do to assist the traditional automotive industry. Responses made by at least 10 percent of the panelists are summarized below.

The U.S. Congress should:	Percent Responding
Establish "fair" trade policies. This includes import restrictions (quotas), local content, "anti-dumping" equivalent taxes, etc.	30%
Permit cooperative R&D efforts with government partnership and/or sponsorship	22
Develop a national manufacturing/industrial policy	17
Relax legislated regulations, develop legislation based on technical realities	12
Develop appropriate fiscal policy to encourage investment and R&D (This includes tax credits and/or accruals for R&D, product design, etc.)	10

The U.S. Congress should not:	Percent Responding
Legislate regulations/requirements that are not technically feasible or are only politically expedient	68%
Restrict market share of imports/quotas by protectionist legislation	15
Allow unrestricted access to U.S. market or tolerate "unfair" trade practices	12

Respondents in this survey concur with those in the 1992 Delphi VI study regarding the role of government in coordinating legislation, government agencies, and other policy activities, and also the need for regulation based on technical considerations.

Panelists are divided on the role of government in managing trade and foreign domestic investment in this forecast. In the 1992 Delphi VI survey, panelists placed a high emphasis on establishing fair trade policies.

Comparison of forecast: MAT-7

There is some difference of opinion in this area between technology and materials panelists. The common questions are summarized below.

The U.S. Congress should:	Percent Yes Votes	
	TECH	MAT
Coordinate legislation, government agencies and other policy activities	91%	76%
Regulate based on technical considerations	72	54
Increase gasoline prices	67	51

The technology panelists view the involvement of Congress much more favorably than do materials panelists in the areas of coordination of legislation, increasing gasoline prices and regulating based on technical considerations. This difference may be a result of a more direct involvement in meeting standards by the technology panelists.

Strategic considerations

The general theme of panelists' responses is that the government and industry need to work together to support and develop a strong automotive industry. This is seen as providing the environment for fair, but not managed, trade. The need for open lines of communication between

industry and government is strongly expressed. Torte liability reform is an area where government assistance is requested.

Government plays a significant role in determining the strength or weakness of the automotive industry, as well as industry in general. The ability of industry and government to work together will shape the future of the automotive industry. Recent activities by both government and industry on a number of fronts is highly positive, particularly if politics as usual can be set aside. It is imperative that we use all of our resources (human, financial and technical) effectively.

TECH-18 What vehicle systems are made more expensive or compromised as a result of differing international standards/regulations?

Vehicle Systems	Responses
Emissions, fuel differences	**24%**
Emission control systems	10%
Powertrain—calibrate for different fuels, test cycles	9
Fuel systems—tanks, pumps	5
Safety—Miscellaneous	**14%**
Brakes; Bumpers; Safety—dummy differences, damageability, wipers; Structure—dynamic side impact	2% each
A-pillar—Visibility standards; Body structure; Crashworthiness—restraints; occupant protection; Safety; Safety—air bags; Seating—visibility standards	1% each
Safety—Lighting Systems	**12%**
Lighting systems	12
Right-hand Drive	**6%**
RH Drive—Instrument panels, dash panels, air conditioning systems, steering	4%
Air conditioning systems	2
Electrical	**5%**
Remote keyless entry—RF frequencies for Europe	2%
Electrical systems—EMC requirements; Electronics for microprocessor (Complexity); Radios	1% each
Noise	**2%**
Noise—exhaust; Noise—tires	1% each
Miscellaneous	**6%**
Comfort; Performance; Plastic components; Quality systems—ISO-9000, etc.; Speedometer/odometer; Window and sealing—Autobahn speed requirements	1% each

Discussion

The vast majority of responses are in the areas of safety and emissions.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trends from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

There is considerable expenditure of money and human resources to meet regulations and protocols that are different between countries. It is to the benefit of the final customer as well as the automobile manufacturers and suppliers to minimize these differences. Organizations such as The Society of Automotive Engineers can play a significant role in providing a forum to bring together the parties responsible for developing divergent requirements, as well as those responsible for meeting the requirements. This is an ongoing effort that deserves the attention and support of all industry participants, as well as governmental units, to minimize waste. Differing standards are also quasi-formal trade barriers (Japan license plate holders' holes, etc.), but sometimes legitimate.

Global issues such as air pollution can not be solved by one country. As developed countries are lowering petroleum consumption, developing countries are raising it. How do you transfer costs and payments? Global industries offer global opportunities and problems. What will the world look like if China has vehicle saturation/person at even one-half the average developed country rate?

TECH-19 Do you anticipate more, less, or about the same cooperation among automotive companies in the next decade in working to achieve common interests, where 1 = much more cooperation, 3 = about the same and 5 = much less cooperation.

Cooperation Among	Mean Forecast
Traditional U.S. manufacturers	1.6
Traditional U.S. manufacturers and suppliers	1.7
Traditional and foreign-owned manufacturers	3.1

Selected edited comments

- Foreign manufacturers are more interested in market share than cooperation.
- Government regulation should be reduced in the future, thus allowing greater cooperative efforts. The trend in this direction is already apparent.
- More cooperation between U.S. OEMs and suppliers is important and needed. But it requires development of suitable win-win relationships. The current state differs between the three U.S. OEMs.
- There are some things best done as an industry, and automotive OEM/suppliers are realizing this.
- U.S. consortia are becoming popular and will help in areas such as electric vehicle batteries, materials, etc.

Discussion

Panelists forecast increased cooperation between U.S. manufacturers and between U.S. manufacturers and suppliers in the next decade. Cooperation between traditional and foreign-owned manufacturers is not expected to change.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic consideration

Panelists forecast significantly more cooperation between the traditional U.S. manufacturers, and also among the traditional U.S. manufacturers and suppliers. This cooperation is seen as a necessity in the environment of increasing demands and diminishing resources.

Conversely, no change in cooperation between traditional and foreign-owned manufacturers is envisioned. Perhaps the concerns with fair trade create an atmosphere in which cooperation is not seen as being supportive of closer international interactions. In fact, many strong relationships exist today between traditional and foreign-owned manufacturers as evidenced by the many joint ventures in operation today.

TECH-20 Many key elements will form the bases of competition in the next decade. Please circle the appropriate number, where 1 = most important and 5 = least important, to indicate your estimate of the importance the traditional domestic manufacturers will assign to each of these elements.

Key Elements	Mean Rating
Quality/reliability/durability (QRD)	1.4
Cost to the manufacturer	1.5
Sales and service	1.8
Safety	1.9
Purchase price	1.9
Corporate reputation	2.0
New technology/product innovation	2.1
Styling/fashion	2.1
Performance	2.2
Fuel economy	2.2
Environmental responsibility	2.2
Reduced lead time	2.2
Corporate image of good citizenship	2.4
Vehicle ergonomics	2.5
Ride and handling	2.5

Other single responses include (followed by rating):

Competitiveness: 1.0; Concurrent engineering & teamwork: 1.0; Cost of ownership: 1.0; Entering foreign markets: 3.0; Global presence: 1.0; Productivity: 1.0; Recyclability: 1.0.

Selected edited comments

- Global competitiveness will continue to grow in importance. Many companies not getting this message will not survive.
- Purchase price must be defined in terms of value.
- Service to customer is number one. Quality is a given. If you do not have it you will join the 200-odd former U.S. auto companies.
- The buying public and the vehicle manufacturers have and are likely to give different weight to these factors.
- We don't need technology just for technology's sake.

Discussion

In the current survey panelists respond that all of the elements forming the basis of competition in the next decade are at least somewhat important. While quality, reliability, durability and cost to the manufacturer are the highest ranking elements, all are considered to be quite similar in overall importance.

Manufacturer/supplier comparison

Manufacturers and suppliers are in close agreement.

This question has been asked in a similar, but not directly comparable format in previous Delphi surveys. The results from the 1992 Delphi VI survey are presented in the table below. In that survey, the panelists were asked to rank each on the basis of competition from most important to least important, whereas in the current survey panelists were asked to rank on a 1-5 scale, with 1= most important to 5 = least important.

1992 Delphi VI	
Basis of Competition: Key Elements	**Mean Rank (1-8)**
Customer satisfaction	1.5
Responsiveness to market demand, lead time	3.5
Styling/fashion	4.4
New technology/product innovation	4.7
Safety	5.0
Sales and service	5.1
Performance	5.3
Corporate reputation/good citizenship	7.6

Strategic considerations

The challenge of the next decade is to balance all of the elements of competition in the specification, design, manufacture, sales and service of future vehicles.

The basis for competition changes (i.e., new differentiators come forward as older ones become equalized across products) must be kept in mind. If fit and finish is superior for a given producer, it has a differentiator or advantage favoring its products. As most manufacturers bring their products to an equal level of fit and finish, this no longer is a differentiator. However, some factors will always be used by the customer to differentiate products.

TECH-21 **How will rapidly developing countries impact worldwide automotive markets and workforce?**

Areas receiving more than one response are summarized below.

Summary of responses	Number of Responses
Expanded total market	9
Reduced vehicle and component costs	9
Not significant in next decade	5
Increased low cost vehicle demand	5
Increased sourcing from developing countries	4
Increased competition	4
Equalized worldwide wages	3
Expanded global workforce	3
Increased global sourcing	2
New vehicle requirements-proliferation	2

Selected edited comments

- After 2003, new markets will develop fast. Before 2003, markets will be trucks/off road vehicles.
- China will grow rapidly .
- Eastern Europe may be significant as European OEMs invest in local partners (Skoda, etc.).
- Europe and the United States will lose jobs.
- Major markets will be increasingly difficult to crack for developing countries.
- Southeast Asia and Eastern Europe will be very competitive in niches.
- Taiwan will enter the industry very rapidly.
- The market is not as significant as the workforce.
- There should be a higher demand for high efficiency.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Discussion/Strategic considerations

The strategic considerations are summarized in the responses and selected comments. Most panelists expect significant impacts on workforce, market size, sourcing location and competition as a result of the growth of the developing countries.

In addition, patterns of foreign direct investment may be shifted. Opportunities may develop to globalize and gain economies of scale on items on which consumers do not differentiate (i.e., corporate finance and selective components) while localizing what they do (style, ride, etc.) Finally, manufacturers and suppliers will be forced to continually identify new competitors and standards.

Clearly a major challenge for the world's car and truck producers is the ability to fully address the rapidly emerging opportunities around the world. Shortages of capital and critical skills exacerbate the problem and increase the likelihood of partnering to permit substantive involvement in more creative markets. In general, manufacturers could face a competitive disadvantage by not appropriately investing in emerging areas. The sales/marketing potential of the areas is enormous.

Engineering and
Sourcing Issues

TECH-22 What percentage of product design and engineering for North American-produced passenger cars is, and will be, performed in North America and offshore by the traditional domestic vehicle manufacturers?

Performance Site	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
North America	90%	85%	80%	80/90%	75/90%	70/88%
Offshore	10	15	20	10/20	10/25	12/30
Total	100%	100%	100%			

Selected edited comments

- Alliances will move many design and engineering jobs both ways, but mainly away.
- As the industry becomes increasingly global, this distinction will become more hazy.
- Estimates include component/subsystems and assume that Ford and GM will make increased use of foreign division/subsidiaries.
- The Third World will be a new entrant to low cost design (i.e., India, China).
- "World cars" are still way off for the Big Three.

Discussion

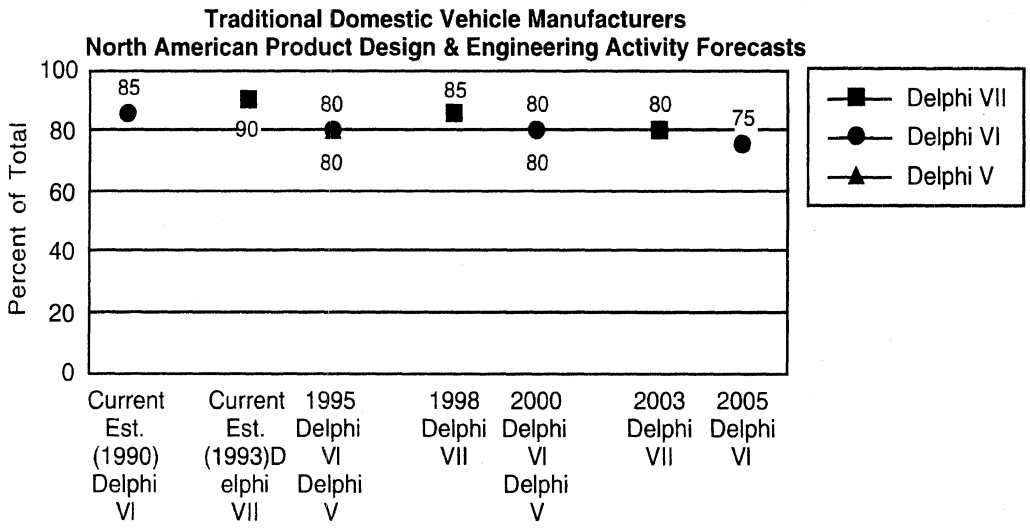
The vast majority of product design and engineering by traditional domestic vehicle manufacturers for North American-produced passenger cars is forecast to remain in North America over the next decade. Engineering outside of North America is expected to increase, however.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

A comparison between this survey and the previous two surveys is summarized in the chart below.



The long-range trend is very similar between the 1992 and 1994 studies, indicating about 75-80 percent of North American product design and engineering will be done in North America by 2003-2005. There is a different current and short term estimate between this survey and the previous two surveys, in that the current estimate for the current year is about 5 percent higher than those forecast in the 1989 and 1992 surveys.

Strategic considerations

There is a consensus between panelists in the current and previous two surveys that the product design and engineering for North American-produced passenger cars by the traditional domestic vehicle manufacturers will gradually be reduced in North America in the next decade. This trend is likely a result of the globalization of the industry, with increased commonization of vehicles and components sold throughout the world, reliance on foreign subsidiaries, alliances between manufacturers and increased use of foreign suppliers. The shortage and cost of some critical skills in North America may also be a factor.

Some issues raised in the move to offshore sourcing of design and engineering are management, coordination and control of the program, as well as the ability to provide differentiation in a world of shared resources. These issues must be addressed before the decision to source offshore is made.

TECH-23 What percentage of product design and engineering for North American-produced passenger cars is, and will be, performed in North America and offshore by foreign owned vehicle manufacturers?

Performance Site	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
North America	10%	15%	25%	5/20%	10/25%	15/40%
Offshore	90	85	75	80/95	75/90	60/85
Total	100%	100%	100%			

Selected edited comments

- Alliances will bring some work here as Japanese use more U.S. engineering/design.
- Increasing North American activity is envisioned.
- It will never get to 100 percent, although Toyota and Nissan are making the commitment.
- This includes engineering and design of manufacturing process and tooling.

Discussion

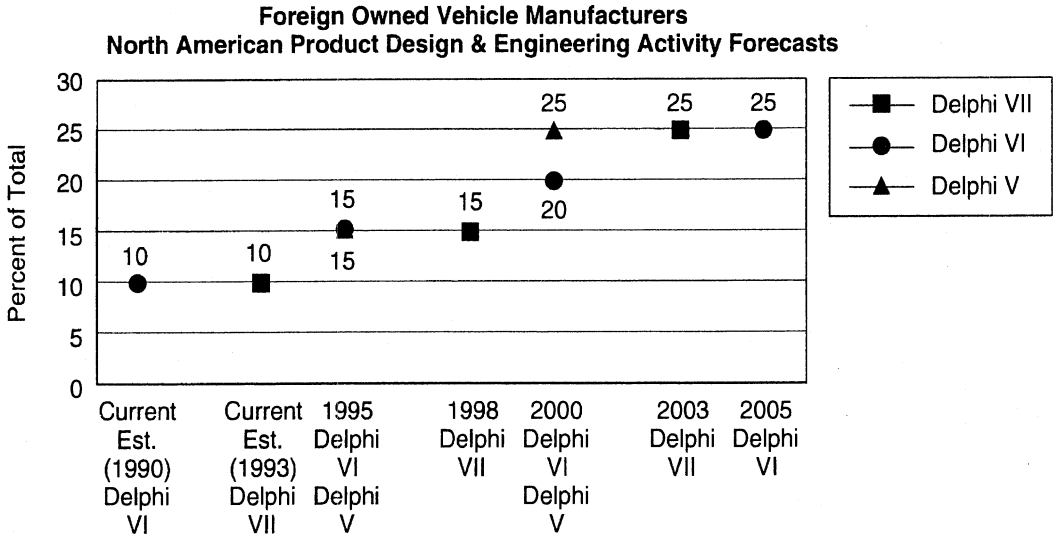
The vast majority of product design and engineering by foreign owned vehicle manufacturers for North American-produced passenger cars is forecast to remain in the home countries of the manufacturers through the next decade, but with an increase in North America.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi survey

A comparison between this and the previous two surveys is summarized in the chart below.



There is generally good agreement between panelists in the last three surveys regarding the direction and magnitude of the product design and engineering for North American-produced passenger cars by foreign owned vehicle manufacturers.

Strategic considerations

The forecast predicts foreign-owned vehicle manufacturers will perform more product design and engineering for their North American-produced passenger cars in North America. This will partially offset the expected drop in engineering effort in North America by the traditional domestic vehicle manufacturers in North America. It is likely that control of major projects by foreign-owned vehicle manufacturers will remain offshore. But increasing political pressure and the need to be near component sources and manufacturing facilities will shift more of the design and engineering to North America.

Evidence of the shift to North America is represented by the minivan joint venture between Nissan and Ford, and Toyota's design of the Camry coupe. Significant design, engineering and testing for foreign owned vehicle manufacturers is also being done by North American engineering service companies.

TECH-24 What percentage of parts, components, and subassemblies, etc., do the traditional domestic vehicle manufacturers source from these regions currently, and what percentage will they source in 1998 and 2003, assuming no domestic content legislation? Please use a dollar volume basis in estimating percentages.

Sourcing for Traditional Domestic Manufacturing Operations	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
Eastern Europe	0%	2%	5%	0/1%	1/4%	2/5%
Japan	10	8	6	5/15	5/10	5/10
North America (United States, Canada, Mexico)	80	78	74	70/87	60/85	63/81
South America	2	2	2	1/2	1/5	1/5
Southeast Asia	2	4	5	1/5	2/5	3/8
Western Europe	5	5	5	3/8	3/7	3/7
Total	99%	99%	97%			

Selected edited comments

- Eastern Europe's quality will take quite a while to get to acceptable levels.
- Japanese figures ignore parts purchased from Japanese factories in the U.S.
- Sourcing in Japan will decrease due to cost considerations. What happens in Eastern Europe depends on where wages go in those areas, civil unrest, etc.
- What about raw materials (e.g., steel, aluminum, etc.)?

Discussion

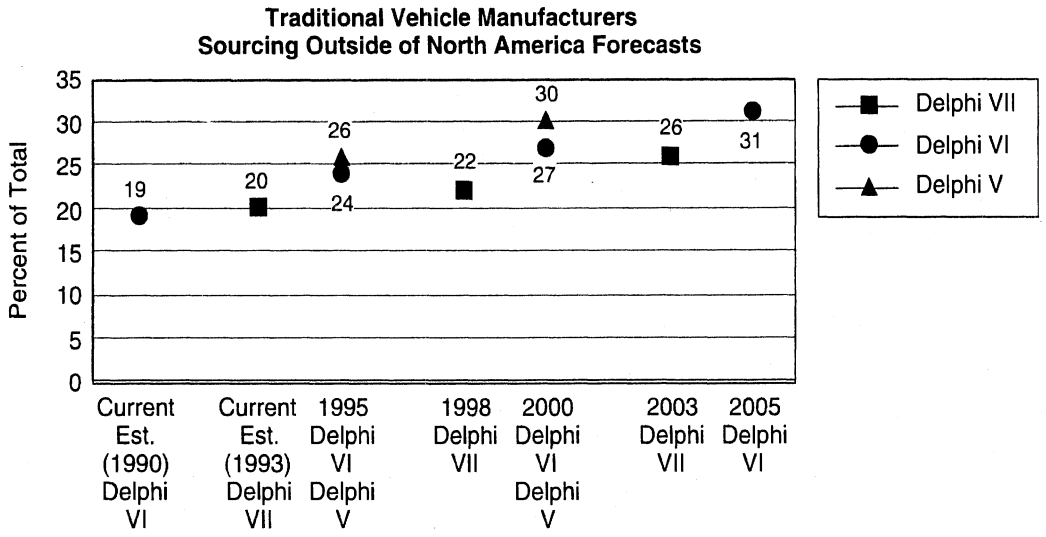
Traditional domestic manufacturers are forecast to source the majority of parts, components and subassemblies from the United States, Canada and Mexico in the next decade. An increasing percentage is expected to be sourced outside of North America, however, including increases in Southeast Asia and Eastern Europe.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi survey

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



The forecast for the amount of sourcing outside of North America by the traditional domestic vehicle manufacturers has declined in each of the past two surveys.

The forecast percentage sourcing to each country or region outside of North America has decreased in line with the overall total.

Strategic considerations

Worldwide sourcing is a very complex issue and is controlled by many factors. Among these are cost, foreign exchange rates, union contract agreements, political pressures, technical competence, shipping costs, proximity to final assembly and engineering, quality, supplier flexibility and joint ventures. In the extremely competitive environment of the automotive industry, the vehicle manufacturer that manages these factors the best will see the results in increased profits.

Issues that must be considered and managed as sourcing is moved between countries are capacity utilization, supplier relations, tariffs, foreign exchange and information management. Considering the forecast for increased sourcing from Eastern Europe and Southeast Asia, political stability and change may also be a factor.

TECH-25 What percentage of parts, components and subassemblies, etc., do the North American production operations of foreign-owned vehicle manufacturers source from these regions currently, and what percentage will they source in 1998 and 2003, assuming no domestic content legislation? Please use a dollar volume basis in estimating percentages.

Sourcing for Foreign-Owned Manufacturing Operations	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
Eastern Europe	0%	0%	0%	0/0%	0/2%	0/5%
Japan	63	55	45	50/70	36/60	30/58
North America (United States, Canada, Mexico)	25	30	35	15/40	20/50	25/55
South America	0	0	2	0/1	0/2	0/5
Southeast Asia	5	7	9	1/10	2/10	3/10
Western Europe	1	2	1	0/5	0/5	0/5
Total	94%	94%	92%			

Selected edited comments

- Eastern Europe's quality will not meet Japanese standards.
- Increasing North American content will be a political necessity, facilitated by increased availability of high quality/low cost suppliers.
- There is very poor data available.

Discussion

The North American production operations conducted by Japanese-owned vehicle manufacturers are expected to continue sourcing a major fraction of parts, components and subassemblies from Japan over the next decade. An increasing percentage is forecast to be sourced in North America, however. Sourcing from Southeast Asia is also expected to increase, as it was from domestic manufacturers.

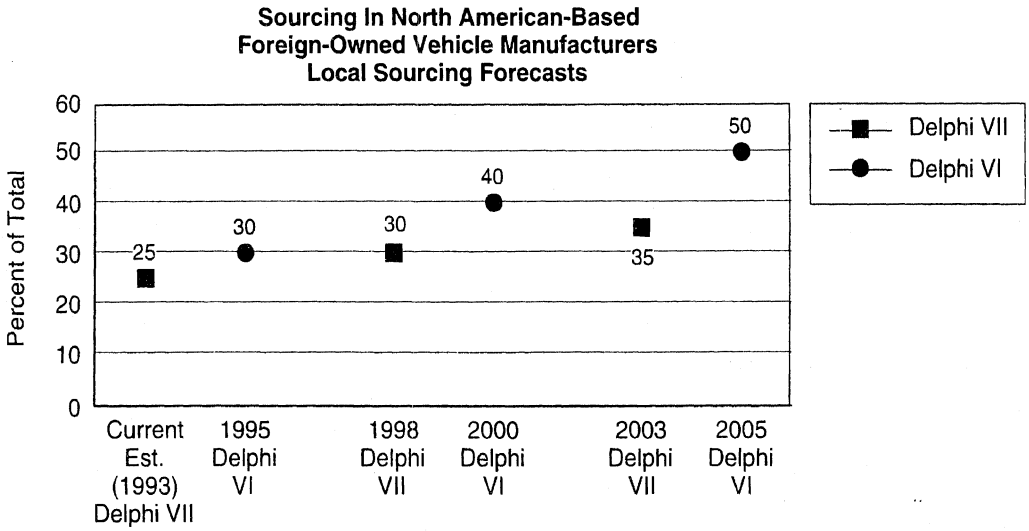
Manufacturer/supplier comparison

Responses for manufacturers and suppliers are very similar. Suppliers, however, forecast more sourcing from Southeast Asia and Western Europe, as shown below.

Sourcing for Foreign-Owned Manufacturing Operations	Current Estimate		1998		2003	
	Manufacturers	Suppliers	Manufacturers	Suppliers	Manufacturers	Suppliers
Southeast Asia	5%	10%	7%	10%	10%	10%
Western Europe	1	5	1	5	3	5

Trend from previous Delphi survey

This question was first asked in the 1992 Delphi VI, but was limited to North America and outside of North America. A comparison for North American sourcing is summarized in the chart below.



Panelists in the current Delphi survey forecast less growth in North American sourcing by foreign-owned vehicle manufacturers.

Strategic considerations

The panelists forecast North American sourcing by North American production operations of foreign-owned vehicle manufacturers to remain well below the 50 percent level in 2003. These are reduced expectations relative to those of the panelists surveyed in 1992. This has serious implications relative to the U.S. balance of payments and North American jobs. Even greater impact on North American-owned suppliers may result because of the increased location of foreign suppliers to North America. It can be expected that considerable political pressure will come to bear to change this situation.

Sourcing strategies will likely be significantly different between manufacturers. It is possible that sourcing will change in steplike fashion as production modules of engines, transmissions, etc. become economical. The future direction of CAFE and the impacts of NAFTA may also influence corporate strategy.

It is possible that this forecast will fall short of reality in future years for North American suppliers if the quality and cost competitiveness of North American suppliers continue to improve.

TECH-26 Assuming that the NAFTA (North American Free Trade Agreement) is ratified, what percentage of components and subassemblies produced in North America do the traditional domestic manufacturers and foreign manufacturers source from each country currently and what percentage will they source in 1998 and 2003? Please use a dollar volume basis in estimating percentages.

Components Sourcing Traditional Domestic Manufacturers	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
North American (NA) content						
United States	75%	70%	60%	70/80%	55/75%	50/70%
Canada	15	15	15	10/20	10/20	10/20
Mexico	10	15	20	5/10	10/25	18/30
Total	100%	100%	95%			

Components Sourcing Foreign Manufacturers	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
North American (NA) content						
United States	80%	75%	60%	65/89%	60/82%	50/77%
Canada	10	10	10	5/19	5/18	5/17
Mexico	8	15	20	5/10	10/22	12/30
Total	98%	100%	90%			

Selected edited comments

- Mexican operations will slowly meet Japanese quality standards.
- NAFTA by itself is not enough to move to Mexico. Go to Mexico if your customer needs you there to support his operations or if low capital/high manual dexterity are key to assembly. There will be much more shipping into Mexico if NAFTA passes.
- To complete the picture, it is necessary to consider vehicles assembled in Canada and Mexico.

Discussion

In the next decade, both the traditional domestic and foreign manufacturers are expected to source the majority of components and subassemblies produced in North America from the United States. Mexico is expected to increase its share, however.

Manufacturer/supplier comparison

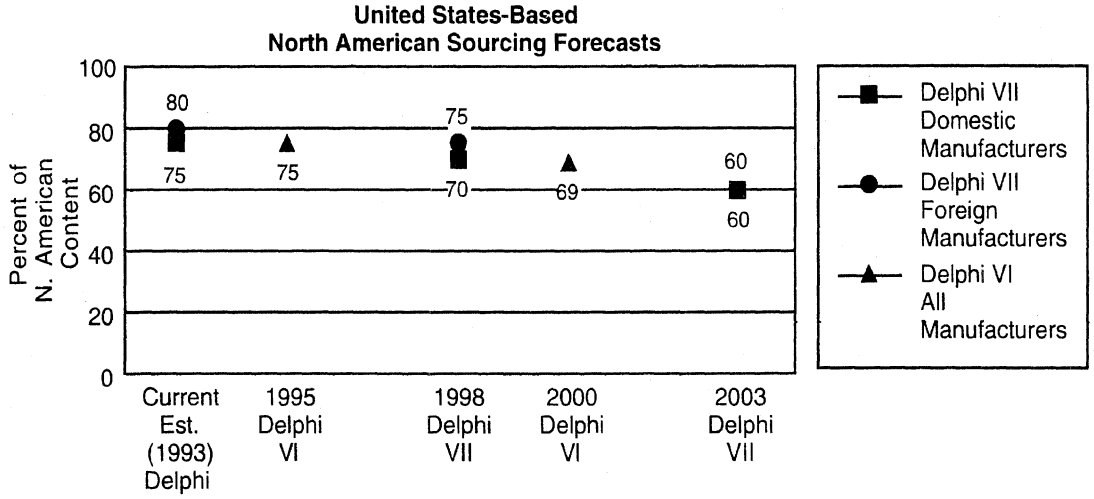
Manufacturers and suppliers are in agreement.

Trend from previous Delphi survey

This question was asked for the first time in the 1992 survey, but did not differentiate between domestic and foreign manufacturers. The results are tabulated below as a percent of total North American sourcing.

Source (1992 Delphi VI)	Assembled Vehicles		Components	
North American Content	**1995**	**2000**	**1995**	**2000**
United States	80%	73%	75%	69%
Canada	13	13	13	13
Mexico	6	13	13	19

Sourcing of components from the United States is summarized in the chart below. The 1992 Delphi VI survey includes foreign and domestic manufacturers.



Expected sourcing from the United States as a percent of total North American sourcing is similar between the current survey and the 1992 Delphi VI survey, and between foreign and traditional domestic manufacturers.

Strategic considerations

Panelists forecast a decrease in sourcing from the United States, an increase in sourcing from Mexico, and a constant level of sourcing from Canada as a percent of total North American sourcing. The net forecast will be a shift in the North American percent of component production from the United States to Mexico with the related shift in the employment market. This is an extraordinarily sensitive political issue presently; particular attention is focused on the auto industry. This requires companies to carefully manage transition for social purposes as well as economic. It should also be kept in mind that as productivity of vehicle and component assembly improves, the advantages of low labor rates in Mexico diminishes as a reason for moving south.

With the passage of NAFTA, the final interpretation and enforcement of rules may have an impact on total North American sourcing. The impact of side agreements must also be considered.

TECH-27 Assuming that the NAFTA is not ratified, what percentage of components and subassemblies produced in North America do the traditional domestic manufacturers and foreign manufacturers source from each country currently and what percentage will they source in 1998 and 2003? Please use a dollar volume basis in estimating percentages.

Components Sourcing Traditional Domestic Manufacturers	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
North American (NA) content						
United States	75%	75%	70%	65/80%	60/80%	60/75%
Canada	15	15	15	10/20	10/20	10/20
Mexico	10	13	15	5/10	10/20	10/20
Total	100%	98%	100%			

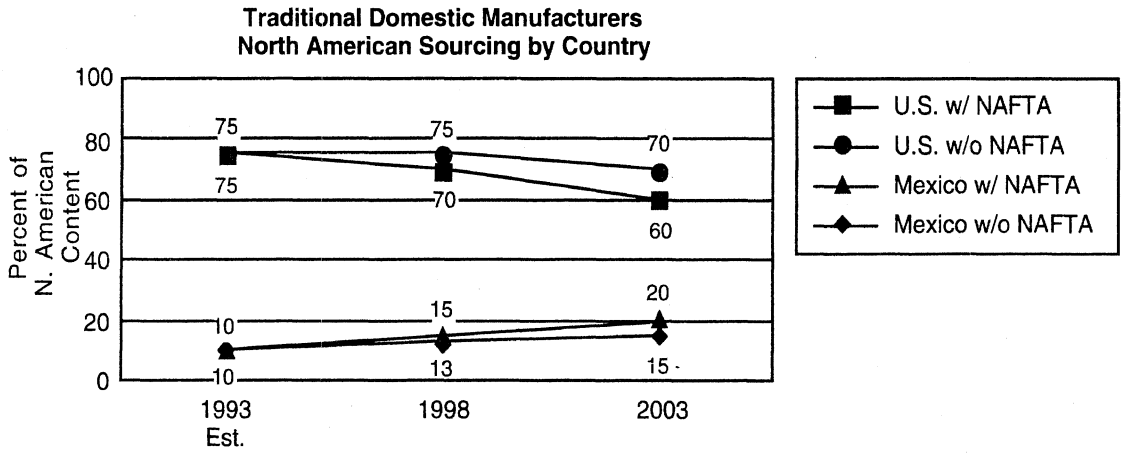
Components Sourcing Foreign Manufacturers	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
North American (NA) content						
United States	80%	80%	75%	65/89%	65/85%	65/80%
Canada	10	10	10	5/19	5/20	5/20
Mexico	8	10	13	5/10	5/20	10/25
Total	98%	100%	98%			

Selected edited comment

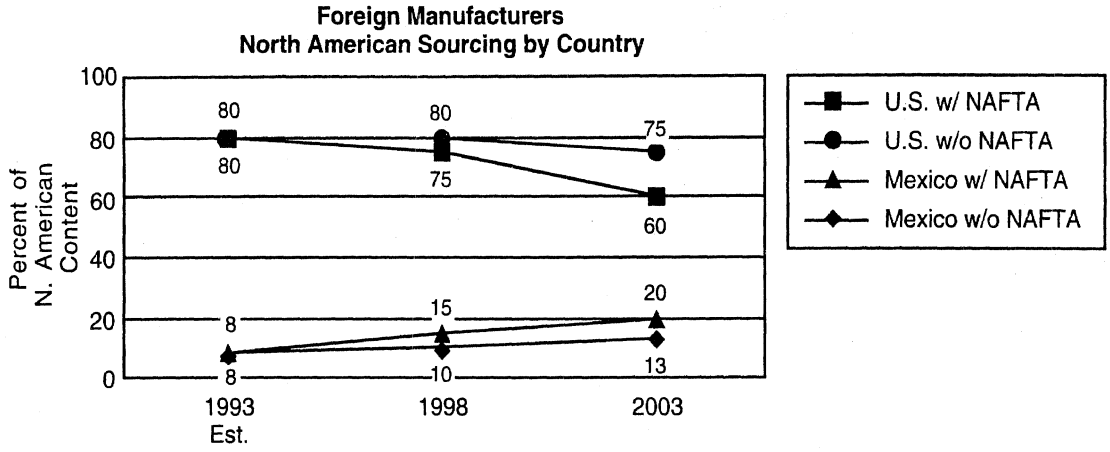
- There is little impact on balance if NAFTA is not passed. There is also a major negative impact on the growth rate of all of North America if not passed.

Discussion

The following table and chart summarizes the impact on component sourcing from the United States and Mexico by traditional domestic manufacturers with and without NAFTA. Canada is not included, as the data indicate no change for Canada with or without NAFTA.



The following summarizes similar data for foreign manufacturers.



Panelists forecast that sourcing from the United States will be negatively impacted by NAFTA for both foreign and traditional domestic manufacturers.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi survey

This question was not asked in a previous Delphi.

Strategic considerations

Considerable data have been presented in support of and in opposition to NAFTA. Many debates have taken place regarding the impact on jobs in the United States. The panelists are clear in their statement that NAFTA will have a significant negative impact on component sourcing from the United States. This loss in U.S. production may be offset in other areas such as the production of capital equipment to be exported to Mexico, but the net long term effect is not obvious. The potential effect on the labor market in the United States is considerable. If the overall market expands with NAFTA, growth could readily offset modest sourcing shifts and their negative impact on employment. It is our opinion that passage of NAFTA will expand the market pie and lead to a net expansion of jobs for all involved parties.

TECH-28 For MYs 1998 and 2003, what percentage of new tooling for North American-produced passenger cars will be sourced in North America?

	Median Response		Interquartile Range	
New Tooling	1998	2003	1998	2003
	75%	70%	60/80%	60/80%

Selected edited comments

- Based on current sourcing, I cannot predict any major sourcing changes.
- Economics will limit application.
- Southeast Asia will win increased business as competitive pressure dictates the need for lower tooling costs.

Discussion

Panelists forecast that there will be a slight decline in the percentage of new tooling for North American-produced passenger cars sourced in North America over the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi survey

This question was not asked in a previous Delphi.

Strategic considerations

Panelists project a modest reduction in new tooling for North American-produced passenger cars being sourced in North America in the next decade. This is a continuation of past industry trends, but at a reduced rate. This trend could change with changes in foreign exchange rates, manufacturing changes, corporate mergers and the continued improvement in quality of machine tools produced in North America. The pressure to contain tooling costs, however, will send the business to the lowest cost producer that can provide satisfactory quality. Southeast Asia will be a formidable competitor in this area.

Further erosion of the machine tool business in North America will continue the loss of employment, unfavorable balance of payments, reduced profits for manufacturers, and the loss of technology and expertise that is a critical factor in defense and overall competitive position. Furthermore, it may be in the long-term interest and competitive advantage of an assembler to keep these capabilities. In addition, jobs or profits lost in this area mean less money available to purchase passenger cars and trucks in North America. Finally, other U.S. industries may take advantage of core capabilities of the automotive manufacturers.

TECH-29 Suggest components/systems that are candidates for standardization within the industry.

Summary of Responses	Percent of Responses
Electrical	**25%**
Batteries	4%
Electrical connectors for powertrain, chassis and body	3
Entertainment/message modules; Modular core ECU (Customize software); Navigation	2% each
Communication protocols; Digital satellite phone system; Drive by wire; Driver information systems data entry systems; Electric switch gear; Electronic communication language; Electronic control architecture; High (>12) voltage bus; High levels of computer interaction; In-vehicle message systems format; Message protocols for information exchange; Microprocessors; Phones; Radar systems for adaptive cruise control; RF devices for safety products; Serial bussing	1% each
Safety	**23%**
Airbags	5%
ABS brake systems	3
Lights	3
Tires	3
Brakes	2
Collision warning system operating characteristics	2
Adaptive cruise control; Seatbelts; Software compilers for safety critical software application; Tire pressure warning	1% each
Engine	**7%**
Emissions control components and sensors; Oil filters	2% each
Air cleaners; Engine accessories; Spark plugs	1% each
Electric vehicle	**6%**
Electric vehicle charging interface	4%
Electric vehicle battery module; Electric vehicle user interface	1% each
Processes	**6%**
Advanced quality planning; CAD design systems; Concurrent engineering; Product development process; Simultaneous engineering; Total quality management	1% each
Miscellaneous	**15%**
Diagnostic systems and standards	4%
Modular heating and air conditioning units	2
Active powertrain mounting systems; Bumpers; Catalyst; Defrost glass; Fasteners; Gas caps; Noise control; Rearview mirrors; Wipers	1% each

Discussion

Numerous components/systems have been noted as candidates for cross-company standardization within the industry. A "champion" is needed in order to begin the process. A supplier or manufacturer may start this process through existing forums.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi survey

This question was not asked in any previous Delphi survey.

Strategic considerations

Many components and systems could be standardized within the industry, with a resulting reduction in requirements for financial and human resources. Cooperative efforts between manufacturers and suppliers can result in standardization in many areas, and the business implications can be profound. A critical point for suppliers is that, as manufacturers standardize or commonize across companies, the net effect may be to drive components toward commodity status.

TECH-30 One of the current buzzwords in the industry relates to business/process re-engineering. Suggest several examples of what this means to you.

Selected edited comments

- Benchmarking other companies and industries is important in improving current methods from within.
- Change the program management process (more rigor and discipline).
- Develop new methods/procedures for handling orders, scheduling builds, processing warranty information, developing new products. etc.
- Do not cut piece cost by 5 percent. Eliminate the part altogether.
- Do not work on enhanced inspection devices. Fix the upstream process.
- Elimination waste in systems—motions, paperwork, etc.
- Every business process is under review to make it more efficient in knowing more precisely the voice of the customer (what he needs and wants), eliminating redundant steps, pushing the approval process to lower levels and eliminating some approval steps, and tying the business process more closely into the engineering and manufacturing processes which are also undergoing re-engineering.
- It means analyzing a process from beginning to end and eliminating steps that have no added value. This applies to manufacturing and engineering as well as business practices.
- It simply means that we need to re-examine how we do all jobs and continue to improve or do more. Do not think how to reduce validation and testing time by 5 percent, think how to eliminate the need to test.
- It's a matter of systems engineering: engineering based on requirements, not egos and opinions.
- Optime the process to support short- and long- term business goals. Re-optimize business analysis methods to consider long- term product/process goals.
- Remove all steps from a business function which do not add value or contribute to the desired outcomes.
- Stop doing stupid things. Focus on the customer, not your empire. Ask, "why do we do what we do?"

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi survey

This question was not asked in a previous survey.

Discussion/Strategic considerations

Many terms are used today that cannot be found in the dictionary, and are thought to mean different things by different people and organizations. "Re-engineering" is one of these terms. The consensus understanding of this term by our panelists is to eliminate waste and inefficiency in every area of the business. At least one manufacturer uses the term "synchronous" in the place of re-engineering. Perhaps this question will help provide common meaning to terms that many have heard but not understood clearly. A common definition is important because many value-added steps are outside a manufacturer, particularly in an environment of increased outsourcing.

An important point to consider is that the process must be continued after the hype of the buzzword has disappeared.

and significantly shorter in Japan. Please give your expectations, in months, of future development cycles–from concept approval through Job One–for the hypothetical re-skinning of high and low volume vehicles, maintaining current hardpoints.

Future Development Cycles Maintaining Current Hardpoints	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
High-Volume Vehicle (production more than 50,000 units/year)						
United States	45	38	34	39/48	35/42	28/36
Japan	36	32	30	30/40	28/36	24/32
Low-Volume Vehicle (production less than 50,000 units/year)						
United States	40	33	30	30/48	26/38	24/35
Japan	30	30	26	24/36	22/32	20/30

Selected edited comments

- "Re-skin" is much different from "all new".
- Will there be any low-volume vehicles built in the United States?

Discussion

For a re-skin with existing hardpoints, panelists forecast a reduction in the future product development time for both the Japanese and U.S. manufacturers over the next decade. The Japanese advantage is expected to be nearly eliminated, however.

Manufacturer/supplier comparison

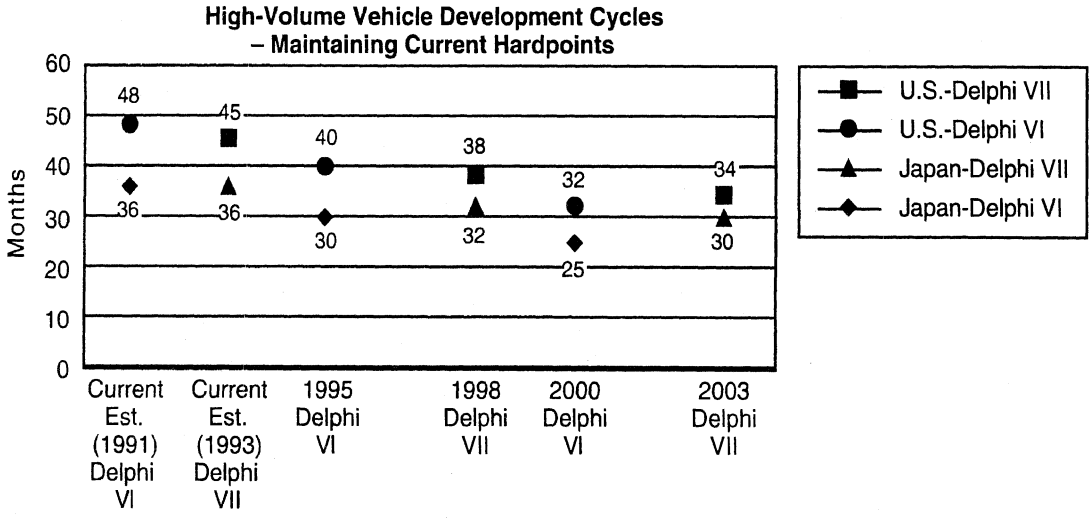
Manufacturers and suppliers are in agreement.

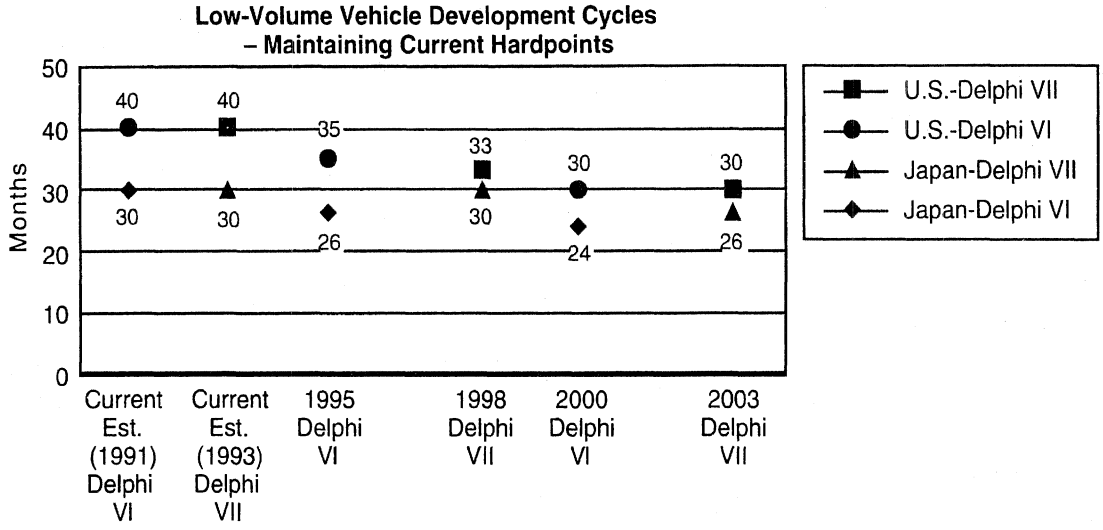
Comparison of forecast: MKT-26a

For high volume vehicles, marketing panelists forecast cycle times that are two-to-three months shorter for all years for U.S. and Japanese manufacturers. Low-volume vehicles were not addressed in the marketing survey.

Trend from previous Delphi survey

Results for the current and 1992 studies are compared in the following charts. Results from prior surveys are similar.





Panelists continue to forecast a reduction in the future development cycle time for both the Japanese and U.S. manufacturers over the next decade. Trends for both high- and low-volume vehicles, however, are for less reduction in cycle time in the current forecast than in the past. Also, a smaller differential between the United States and Japan in the time frame 2000-2003 is forecast in this survey as well as in past surveys. Any comparison between the United States and Japan (or, for that matter, between manufacturers in a given country) is the apparent variation in definition of when the process begins. This is a factor of some concern. We all agree on the end point but not the beginning.

Strategic considerations

In a highly competitive market, the manufacturer that can respond quickly to a rapidly changing market will be at a significant advantage. Current panelists see the development time cycle gap closing between the Japanese and U.S. manufacturers. This factor, combined with declining gaps in the areas of cost and quality, will continue to strengthen the positions of North American manufacturers.

As capital for new programs continues to be or becomes constrained, the average life cycle of a model will increase. This will tend to reduce the advantage for the manufacturer with shorter cycle time. There are also risks associated with rapid cycle time, particularly in the area of reduced product validation time. On the other hand, increased use of computers and improved organizational structure in the design, development and validation phases of the product cycle may allow manufacturers to shorten cycle time without increasing risk. One very interesting issue is the impact of the structural change in the Japanese manufacturers on their product development process, product cycles and vehicle characteristics. There is some suggestion that their processes of the growth-oriented 1980s may not be appropriate for the 1990s. Also, the impact of agile thinking in all its various forms will likely have a profound impact on the product development process.

In many respects, the traditional domestic manufacturers may be on the verge of truly revolutionizing the process through such mundane methods as greater empowerment and better utilization of the supply base. We must keep in mind that in the 1950s the U.S. auto industry was able to bring a car (albeit a simpler product then today's, with fewer models, regulatory requirements and performance demands) from concept to customer in about two years, without computers. True systems thinking is absolutely essential in this area.

A key area likely to have profound impact on product development is information technology in all its various forms. Manufacturers and suppliers must attempt to be at the forefront of rapidly emerging trends. They should consider having a senior executive of information technology, as well as assuring focus on information technology throughout the organization.

TECH-32 Please give your expectations, in months, of future development cycles–from concept approval through Job One–for new platforms that establish new hardpoints for high- and low-volume vehicles.

Future Development Cycles Establishing New Platforms	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
High-Volume Vehicle (production more than 50,000 units/year)						
United States	52	44	38	48/58	40/48	35/42
Japan	40	37	34	36/46	34/40	30/36
Low-Volume Vehicle (production less than 50,000 units/year)						
United States	48	40	36	40/50	36/45	30/40
Japan	37	35	30	32/42	30/38	28/36

Selected edited comments

- Apart from Viper, no U.S. OEM currently plans on less than 50,000.
- Numbers are the same for re-skin because hardpoints and other all-new platform issues should be handled before concept approval (allow approximately one year).

Discussion

For a new platform, panelists forecast a reduction in the product development time for both the Japanese and U.S. manufacturers through the next decade. The Japanese advantage is expected to be greatly reduced.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Comparison of forecast: MKT-26b

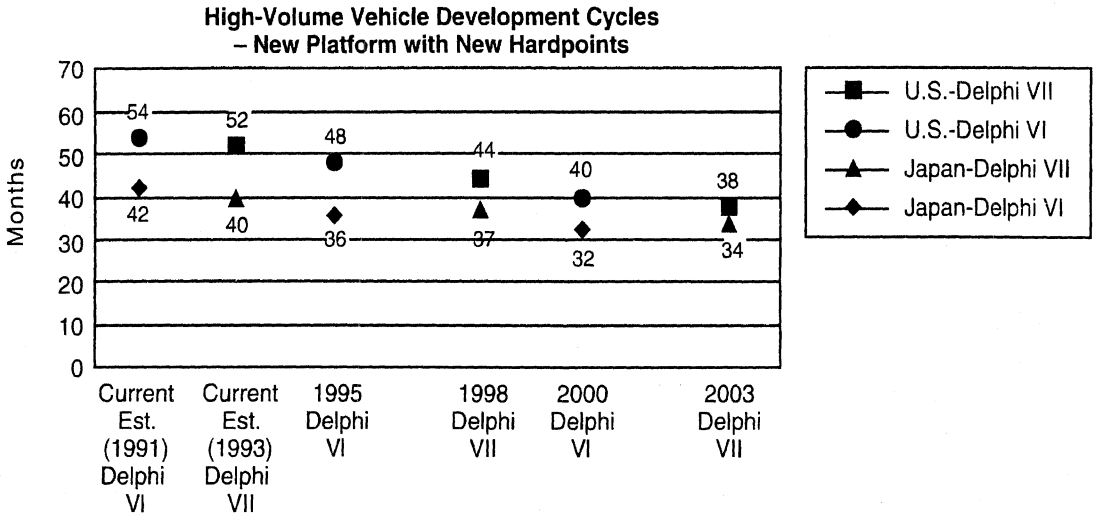
Technology and marketing panelists are in agreement for cycle time in Japan for high-volume vehicles. Results for U.S. manufacturers are somewhat different, however, and are summarized in the table below. The difference may be attributable to the fact that marketing is responsible for a large portion of the program preceding approval of the clay model, but engineering and manufacturing are largely responsible for the program following this point. It is sometimes difficult to assess how long it takes others to do their jobs, and there may be a general tendency to err on the low side. On the other hand, the differences here are not great. They may be a result of differences between companies and/or normal statistical variance of the estimate. Another possible factor may be the general disagreement within the industry regarding when the clock starts.

Low-volume vehicles were not addressed in the marketing survey.

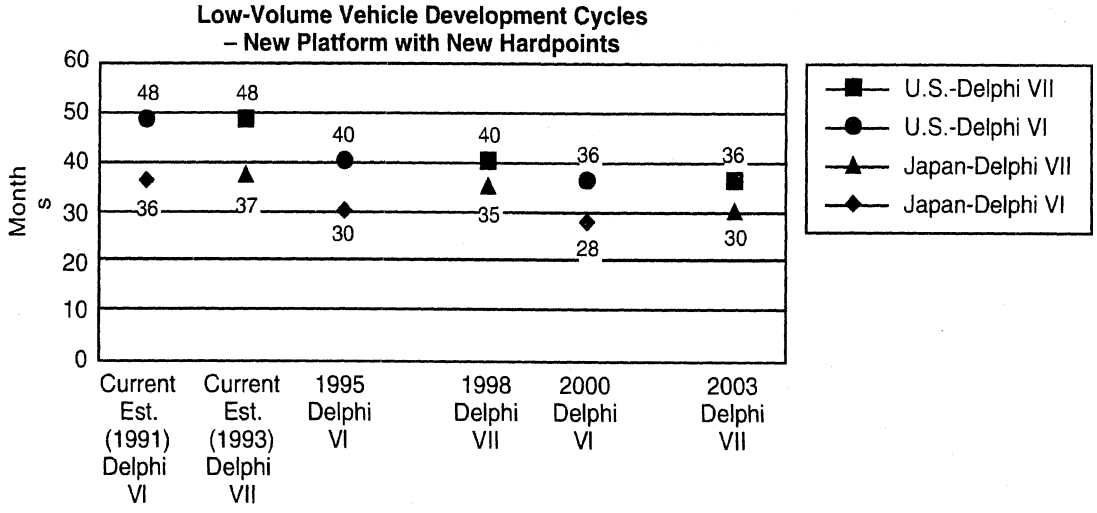
Future Development Cycles U. S. High-Volume Vehicle Establishing New Hardpoints	Median Response		
	Current Est.	1998	2003
Technology panelists	52	44	38
Marketing panelists	48	42	36

Trend from previous Delphi survey

Results for the 1992 Delphi VI and 1994 Delphi VII surveys are compared in the following charts.



Results of the 1992 and 1994 surveys are very similar for high-volume vehicles, with only somewhat less improvement for Japan in the time frame of 2000-2003 indicated in the current survey.



For low-volume vehicles, the current panelists forecast somewhat higher cycle time for the entire period under consideration for both U.S. and Japanese manufacturers. They also project less advantage for the Japanese manufacturers in the time frame of 1998-2003.

Strategic considerations

The statements made in (TECH-31) apply here also.

TECH-33 Product development cycle time from concept approval through production of first marketable vehicle is arguably shorter for Japanese than domestic manufacturers. How significant is each of the following possible sources of this difference, where 1 = very significant and 5 = not at all significant?

Sources	Mean Forecast
Better/more complete definition at concept approval	1.5
Fewer program changes after concept approval	1.7
Supplier role:	
Earlier involvement	1.9
Overall involvement/support	2.1
Capability	2.5
More R&D time prior to concept approval	2.1
Cross-functional design and engineering teams	2.2
Shorter tooling time	2.3
More efficient design process	2.5
Greater use of carryover parts	2.7
Differences in definition of start time	3.0
Design complexity	3.1

Other single responses include (followed by ranking):
Application of computer technology: 3.0 ; Cost of capital and company cash flow: 2.0 (1993), 4.0 (1998+); Culture of urgency: 1.0; Dollar resources: 2.0; Government assistance: 2.0; Labor work rules, contract restrictions: 3.0; Management direction and plan: 2.0.

Selected edited comments

- MITI involvement is a significant factor.
- Tool suppliers are typically owned/controlled by Japanese manufacturing.

Discussion

There has been much discussion in the industry regarding this issue. From the previous two questions, panelists indicate that the advantage enjoyed by the Japanese in this area is diminishing and will continue to do so in the next decade. Panelists believe that each factor presented, in addition to those offered as comments, contribute to the advantage held by the Japanese.

The most significant factor noted is better and more complete definition at concept approval. The next most significant factor is closely related to the first: fewer program changes after concept approval. Both issues involve management participation early in the process of defining the vehicle, including making decisions that are well supported by the voice of the customer. Management must also take into consideration all aspects of the business. These aspects include but are not limited to total vehicle piece cost, required capital investment, quality, manufacturability, styling, ergonomics, performance, noise and vibration, supplier relationships, geography of assembly plant and suppliers, safety, fuel economy and vehicle emissions. Decisions made early—with good supporting data and thoughtful consideration by all involved—are much less likely to be changed later. Apparently the Japanese are better at this early stage of the program. Panelist believe that the domestic manufacturers are getting better at this process and are closing the gap.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi survey

This question was not asked on a previous Delphi.

Strategic considerations

Comments made in the previous two questions regarding product development cycle time apply here also. It is clear that a well-defined and disciplined process is essential. The American propensity for "ad hocness" may be a reflection of their often-revered creative thinking. It can certainly help the process if this thinking is done within the proper context, but it can hurt when the context is missing. We would also reiterate how important empowerment is to facilitate the process. Consistent with this is the great importance of delegating not just responsibility but also authority. Balance is also important. Empowerment encourages individual thinking, yet the resulting ad hocness is identified as a weakness.

Streamlining the development process should also be considered. We are generally predisposed to expanding our groups to the point where bureaucratic quagmire can absorb a significant fraction of the group's energy. Chrysler appears to have broken the U.S. paradigm that we should double the size of a staff to double the output. In fact, they discovered that cutting the size by one-half doubled the output by forcing greater discipline, streamlining communication and leveraging all resources more effectively. This often requires redefining the role of entire groups (such as purchasing) as well as the role of suppliers. Doing so requires better purchasing systems, ability to give up control, etc. You can't leverage outside resources by simply cutting internal staffs in half. The external interface becomes critical, and companies typically even have trouble with internal interfaces.

TECH-34 Where do you see product/process technology leadership currently and in the future? (Please rate from 1-5, where 1 = very high technology and 5 = low technology).

Countries	Product Technology		Process Technology	
	Today	MY 2003	Today	MY 2003
United States	2.0	1.7	2.3	1.8
Europe	2.4	2.1	2.6	2.4
Japan	1.6	1.6	1.5	1.5
Southeast Asia	3.8	3.1	3.7	3.1
South America	4.1	3.8	4.1	3.7
Eastern Europe	4.5	3.8	4.5	3.8

Selected edited comments

- BMW's aluminum efforts are leading the world.
- Emphasis must be placed on process technology, not necessarily automotive, if the United States is to be competitive in producing vehicles.
- Japan will shift focus slightly from product to process technology acceleration.
- The only new process technology coming from the United States is agile, which is a banner with no real definition or specifics. When we define it, then it may change our leadership position.
- The United States is driven harder by regulation.
- The United States research labs will surprise our fellow competitors. Some effort will be joint efforts.

Discussion

Panelists rate Japan as being the leader today in both product and process technology. The United States is a near second in production technology and a somewhat further second in process technology. Panelists expect this gap to narrow in the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement with the exception of the areas noted in the following table.

Country	Product Technology Today		Process Technology Today	
	Manufacturers	Suppliers	Manufacturers	Suppliers
South America	4.5	3.7	4.4	3.7

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

Joint ventures play a role in the interchange of technology between manufacturers. Today, this accounts for only a small fraction of the total vehicle models in the marketplace.

The education systems in the various countries are an integral partner with industry in providing the foundation on which technology is built. Education at the college level is as good in the United States as anywhere in the world. The education system prior to college does not produce the same excellent results in the United States as compared to other countries such as Japan, however. This is a complex issue with many potential explanations such as differences in parental support of the student and the length of the school year.

Another issue in the United States is the diversion of many bright students to careers that have greater financial rewards and/or carry greater peer prestige than the sciences and technology.

The long-term future of a nation is only as secure as its ability to maintain technological competitiveness. Maintaining a high level of technological competence will assure that jobs in the design and manufacture of automobiles and components will continue to be available at home. Maintaining this technology base is also critical to our national defense.

It is imperative that industry work with educators and the government to strengthen a nation's technological capability.

TECH-35 What new technologies or procedures will be used in the next decade to reduce product cycle timing, reduce vehicle, component, design/development, and other cost, and improve quality?

Reduce product cycle timing:	Percent of panelists
Computers	**75%**
CAD	17%
CAE	15
Computer modeling of components and system interactions and relationships	15
CAM	10
CAD/CAE/CAM integration improvements	6
Finite element analysis	4
Networking improvements	2
Computer validation; Data systems integrated; Expert systems; Math modeling--increased use; Parts databases-standard, user friendly; Vehicle imaging—full-size for theme development	1% each
Administration/Organization	**26%**
Teams—cross functional	16%
Teams—empowered capable leader	2
Freeze dates enforced; Lead times emphasized; Management discipline improved; Organization stability; Organizational structure--more focused; Platform concept; Team co-location; Teams—operation process improvement	1% each
Facilities	**11%**
Prototyping—rapid (including stereo lithography)	9%
Electronic conferencing; Test facilities/equipment improvements	1% each
Product definition process	**8%**
Bookshelfing designs	3%
Product definition improvement	3
Formalized concept selection and approval process; Planning process improved	1% each
Suppliers	**8%**
Sourcing early	4%
Suppliers—closer relationships	3
Suppliers—smaller, quicker-to-respond, grouped into virtual organizations to supply modules	1
Design process	**6%**
Design failure mode analysis; Design freeze early; Engineering process—more disciplined and productive; Mulling (proving) technologies before introducing in new applications; Parts—more carryover; STEP/PDES engineering document standard	1% each
Manufacturing	**5%**
Manufacturing--agile	4%
Modular construction	1
Tooling	**3%**
Die tooling —faster	2%
Die development—half scale, plastic dies; Tooling time reduced	1% each
Education/Training	**2%**
Tasks and critical interactions—more complete definition; Training—world class	1% each

Discussion

Reduce product cycle timing

The greatest response by far to reduce product cycle timing is with regard to the use of computers. Computers are expected to expedite cycle timing from the beginning of the process and continue throughout the analysis, design, development and validation of the vehicle. Computers will enhance manufacturing/engineering interfaces, prototype modeling and a host of other areas in the process. Companies that lead in this area will lead in cycle timing. It should be noted that many of the advances in computers will be in software, an area in which the United States is a leader. The rapidly developing science of information technology requires careful watching.

The next most important area mentioned is administration/organization. This is discussed in previous questions relative to cycle timing with regard to product definition, but many additional organizational issues are raised by the panelists.

Most of the responses do not offer new technologies or procedures, but rather improvements and advancements in those currently in use. This is in line with the philosophy of continuous improvement that has been so successful for the Japanese.

Reduce vehicle, component, design/development and other cost:	Percent of panelists
Computers	**42%**
Computer simulation/modeling	17%
CAE	8
CAD/CAM	6
Integration of CAD/CAM/CAE	4
Stereo lithography	4
CAD—3D; Computer software; Smarter work stations	1% each
Design process	**26%**
Design for manufacturability/assembly (DFM/DFA)	5
Parts commonization	4
Cycle time reduced; Specifications—more complete; System integration improved; Up-front requirements improved; Bookshelving designs	2% each
Carryover components better utilized; Concurrent, direct and simultaneous engineering; Design advisors; Families of components usage increased; Modular subsystem design and assembly increased; STEP/PDES engineering document standard; Subsystems modularized and outsourced	1% each
Suppliers	**17%**
Increase participation in design/development	9%
Full service	4
Early involvement	2
Presourcing agreements; Reduced number	1% each
Administration and organization	**10%**
Teams—cross functional	4%
Stability of functional expertise/applications in organization increased	3
Integrated product and manufacturing engineering; Product focus at corporate level improved; Technology management and use of supply base improved	1% each
Facilities	**5%**
Rapid prototyping	4%
Test facilities improved	1
Product definition process	**3%**
Product deproliferation	2%
QFD with more "voice of the customer" input	1
Tooling	**2%**
Rapid tooling; Tooling prototypes	1% each
Manufacturing	**1%**
Process control more efficient	1%
Other	**10%**
Domestic industry technical collaboration; Materials; Workforce reduced as volume increases	2% each
CIM; Cost reductions mandated; Fewer platforms; Hardware in loop simulation; Labor contracts revised from NAFTA; Outsourcing to lower wage countries; Plastics—increased use; R&D infusion from government/defense resources	1% each

Discussion

Reduce vehicle, component, design/development and other cost

Computers and information technology lead again as the most significant factor in this area. Techniques in the design, development, analysis and manufacturing process that will reduce cycle timing will also reduce cost.

The next most significant area noted is the design process. The total process used to define, design, manufacture and bring the product to market controls, to a large extent, the cost of the vehicle. A good process will bring to market a low-cost vehicle.

Improve Quality	Percent of panelists
Design/development process	**17%**
DFM/DFA	2%
Accelerated testing; Design for quality; Designs simplified; Development cycle more structured; Development groups involved early; Lessons Learned applied to next program—improved technical memory; Procedures standardized; Process capability understood; Product development leadtimes reduced; Prototype stages (blocks) increased; Prototyping earlier; Reduce inventing during design; System design specifications developed and utilized; Systems engineering improved; Testing of systems/subsystem improved	1% each
Quality/reliability techniques/methods	**17%**
Statistical tools improved	4
TQM practices increased	2
Emphasis on long life; FMEA; Long-term reliability testing emphasized; OEM attention to detail; Reliability and quality growth management function early in the design, development and manufacturing process; Reliability engineering; Taguchi methods; Test-to-failure; Total dimensional control system based on variation simulations analysis developed; Validation methodology improved; Variation management	1% each
Computers	**12%**
CAE	5%
Analysis, simulation, modeling	2
Analytic prototypes; CAD—3D with up-front analysis; CAD/CAM; Computer software; Data systems integrated; Rapid prototyping and tooling techniques	1% each
Product definition process	**9%**
QFD	5%
Proliferation reduced	3
Customer driven	1
Administration/organization	**7%**
Product focus at corporate level improved	2%
Employee empowerment; Engineering and manufacturing groups, increased cooperation; Individual empowerment at low levels increased; Management attention increased; Organizational stability	1% each
Manufacturing	**7%**
Variation reduced	2%
Automated manufacturing increased; Process monitors improved; Start-up time to full production lengthened; Synchronous plant floor methods; CIM	1% each
Education	**3%**
Workforce training increased	2%
Design advisors	1
Suppliers	**3%**
Earlier involvement	2%
Commitment for life of the product	1
Facilities	**1%**
Facilities improved	1%
Other	**12%**
Process control improved at all steps from engineering to sales	5%
Continuous improvement	2
Benchmarking; Cycle time reduced; Labor-management relations improved; Materials improved; Real, honest review of quality and a cost/benefit analysis	1% each

Discussion

Improve quality

The design/development process and quality/reliability techniques and methods are the most frequently mentioned areas necessary to improve quality. A quality product can only materialize if the design is robust such that systems interfaces function properly, parts fit together every time in an assembly plant environment, and the design has been adequately analyzed and validated to assure durability.

Quality/reliability techniques and methods must be understood by everyone involved in bringing the product to market. Dr. W. Edwards Deming has received belated attention in this area and has contributed significantly to the awareness of entire organizations to the basic requirements of a quality product. The Japanese have long understood and embraced the philosophy of continuous improvement. The domestic manufacturers are rapidly learning the benefits of these techniques and are seeing the positive results of their effort.

Strategic considerations

The various ideas, methods and techniques addressed in this question appear almost overwhelming and beyond the scope of most individuals and organizations. How can we even manage such complexity? Yet their mastery seems essential to survival. Team system and process thinking, discipline and a fundamental emphasis on knowledge are critical. Ample evidence of success for those who integrate this thinking into their business, suggests we all should attempt it. A message to upper management can be found in the words, "Let my people go."

TECH-36 There is discussion of so called "super fluids" as applied to vehicles. Suggest examples of these fluids and how they might influence future vehicles.

Selected edited comments

- An example would be fluids that adapt characteristics based on environment.
- Brake fluids with higher temperature capabilities and the ability to shed moisture would qualify.
- Electrorheological fluids could be used as simple control devices, assuming stability and cost issues get resolved.
- Electrorheological fluids could be used in transmission torque converters, valve lifter function, etc.
- Low viscosity—high lubrisity fluids could improve the efficiency of virtually all mechanical components using lubricating fluids--engines, steering pumps and air conditioner compressors—thus reducing the power consumption due to friction losses and improving fuel economy.
- Lubrication fluids may never need changing.
- Magnetorheological clutches, valves and dampers should be included.
- Super fluids could enhance brake system cooling, leading to smaller brake systems.
- Synthetic engine/transmission fluids that really impact and improve fuel economy and service requirements would be welcome.
- The category includes fluids which change mechanical properties with changing electric current/voltage. These would apply to active hydraulic controls and engine emissions at low ambient temperatures.
- The only super fluids I am aware of are those that change viscosity in the presence of electric fields. These are being developed for use in chassis systems (shock absorbers and engine mounts) and some discussion for accessory drive clutch mechanisms. What do you mean by super fluids? It there an accepted definition?

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Discussion/Strategic considerations

As evidenced by the responses, the term "super fluids" can refer to a number of technologies. A breakthrough in the capability or cost of any of these fluids could have a dramatic impact on the automotive industry. These breakthroughs may be taking place within the industry today. In fact, significant advances become more probable as major new technical resources (e.g., national laboratories) begin to address automotive issues. These developments could take place within companies, in national laboratories or in a consortium. It is important to stay abreast of developments as they occur. Of course, this raises the question of how to track emerging technology. This is a critical issue. In this day of fast-paced change, how do you find the real nuggets? How do you access technology outside of your own environment?

TECH-37 The term "smart materials" is used in the industry. Please give examples of smart materials and possible uses for these materials.

Summary of responses

- An example is Magnetostrictive materials that could be used in valves and solenoids.
- Biometric polymers are one example.
- Electric motors could be used for window lift regulation
- ER fluids and catalysts could qualify.
- Fiber optics as sensors in structure and systems and computer internal sensors would be a "smart" material.
- I would include Memory material—lock in a polymer bond structure or alloy at some condition and when you get back to those conditions the material snaps back into shape. Applications are self repair fenders and fascias, actuators, assembly and sensors
- Photosensitive materials for mirror and glass darkening should make the list.
- Piezoelectric ceramics could be used in actuators
- Smart foam for more comfortable seat cushions and armrests would be a good example.
- Strand-oriented composites for high strength in direction are needed.
- Thermosensitive materials could be used for automatic venting systems.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Discussion/Strategic considerations

The comments from the previous question about super fluids apply to smart materials also. Breakthroughs could happen at any time and dramatically change segments of the industry. It is imperative to keep abreast of changing technology in these areas.

Opportunities exist for suppliers to obtain a competitive advantage or develop a new product. New suppliers may be added to the auto supply base. Opportunities also exist for manufacturers to provide consumer value-added or product differentiation.

TECH-38 **Please estimate application rates for electrorheological (ER) fluids for the following features in 1998 and 2003.**

Systems/Components	Median Response		Interquartile Range	
	1998	2003	1998	2003
Accessory drive components	0%	3%	0/2%	1/10%
Active suspension components	1	5	0/5	0/10
Engine mounts	2	10	0/5	4/15
Shock absorbers	2	8	0/5	2/12

Other responses include:
Non-vehicle controls: 1998: 5 percent; 2003: 15 percent.
Truck cab mounts: 1998: 2 percent; 2003: 15 percent.

Selected edited comments

- ER fluids will be used in shocks as part of semi-active suspensions for vehicles.
- This question really depends totally on raising the temperature/power dissipation of the fluids.
- This technology is still very expensive.
- Until breakthrough happens in thermal stability, there will be few applications. It is hard to predict timing for breakthroughs.

Discussion

Electrorheological fluids are expected to find very limited applications in the next decade.

Manufacturer/supplier comparison

Suppliers project somewhat larger use of electrorheological-rheological fluids, as indicated in the following table. It is possible that these fluids are in the development stage at the suppliers, and that the complete potential or state of development is not fully recognized by the manufacturers.

Systems/Components	1998		2003	
	Manufacturers	Suppliers	Manufacturers	Suppliers
Accessory drive components	0%	5%	3%	5%
Active suspension components	1	5	2	10
Engine mounts	1	5	10	10
Shock absorbers	2	5	8	10

Trend from previous Delphi surveys

This question was first asked in the 1989 Delphi V survey as an open-ended question regarding potential applications for electrorheological-rheological fluids. The components/systems most widely mentioned in that survey were included in a question in the 1992 Delphi VI study. This question was carried over to the present study. The results are very similar.

Strategic consideration

Electrorheological fluids have some fascinating potential applications. Technical problems prohibit their near-term use, but our panelists foresee limited application by the end of the decade. Technical breakthroughs could accelerate application. Clearly this is a technology that warrants careful consideration, since the time from breakthrough to commercialization can be surprisingly short. In addition, perhaps someone has already made the breakthroughs and most don't know about it. We must be prepared for surprises as we should be prepared to give surprises.

TECH-39 What new technologies are likely to emerge in the next decade that will have significant impact on the following vehicle systems?

Engine	Percent of Responses
Materials	**23%**
Ceramics—advanced	10%
Lightweight materials	6
Composites	3
Aircraft materials usage; Aluminum; Mass reduction; Piston material improved—lighter/stronger, for reduced engine out emissions	1% each
Valvetrain	**21%**
Variable cam timing, lift, or phasing	10%
Continuous variable valve timing (CVVT) with computer control	6
Camless engine	4
Valves—lighter, faster acting with valving rather throttle control of airflow	1
Control systems	**13%**
Adaptive control systems	3%
Control technologies— new	3
Electronic throttle control	3
Air assist injection; Fuel, ignition and combustion control with more sophisticated computers; Fuzzy logic; Improved airflow control	1% each
Engine configuration	**13%**
Two-stroke	10%
Electric vehicles, including hybrids	2
Variable displacement engines	1
Sensors/electronics	**9%**
Electronics—improved	3%
Sensors— advanced	3
Gas sensors to improve engine control; Linear oxygen sensors; Sensor technology—new	1% each
Fuels	**4%**
Alternate fuels	4%
Friction/lubricants	**4%**
Lubricants—improved	2%
Friction reduced	2
Catalytic converters	**3%**
Heated catalytic converters	3%
Other	**20%**
Direct fuel injection	6%
Batteries for electric vehicles	3
Lean burn (requires catalyst)	3
D.I. diesel; Engine-out emissions reduced; Improved combustion management; Low top land pistons; Merging of diesel and gasoline engine technologies for fuel consumption reduction; Onboard monitoring systems; Temperature control inside and outside more optimized; Thermal conservation	1% each

Discussion—Engine

Ceramic materials, two-stroke engines and variable cam timing, lift or phasing receive the greatest number of responses relative to new engine technology. Ceramic materials and two-stroke engines also received the greatest response in the 1992 Delphi VI study. The penetration of ceramic engine components is addressed in TECH-86. Market penetration and obstacles to introduction of two-stroke engines are addressed in TECH-71 and 72. Variable timing and lift control of valves is addressed in TECH-79.

Transmissions	Percent of Responses
Number of speeds increased	**36%**
CVT	15%
Five-speed automatic	10
Six-speed automatic	5
Six-speed manual	5
Beltless CVT	1
Electronics	**13%**
Electronic controls	7%
Computer controlled automatic transmissions	3
Direct electronic shift control; Drive-by-wire—closed loop shift management; Electronically controlled converter clutch	1% each
Materials	**13%**
Fluids—super	5%
Magnesium use increased	3
Variable torque converter through electrorheology	3
Composite materials; Pyrolytic carbon for longer life and better clutch engagement	1% each
Other	**9%**
Efficiency improved; Slip starter clutches, electronically controlled; Torque converters eliminated	3% each
Automatic manual transmission; Fully automatic—fully mechanical transmission; Integration with engine; Neutral idle for fuel economy; Refinements and evolution; Viscous damper	1% each

Discussion—Transmission

The most frequently mentioned item for new transmission technology is the continuously variable transmission or CVT. This is somewhat surprising, in that panelists forecast only 1 percent penetration of the CVT by 2003 in TECH-88. Perhaps 1 percent is a significant first step for a technology that is almost nonexistent today.

The five-speed automatic transmission is the next most frequently mentioned. The application rate of this transmission is also addressed in TECH-88, and is projected to be 5 percent in the year 2003. Because of increased cost, the most likely applications in the next decade will be in luxury vehicles. Increased fuel economy requirements could accelerate this application rate.

Electronic controls are the next most frequently mentioned. In TECH-91, Panelists predict 90 percent application of electronic controls to transmissions by 2003, so electronic control may not really be viewed as a new technology. Improved pleasability and fuel economy will drive the application of this technology.

Body	Percent of Responses
Materials	**52%**
Aluminum	14%
Polymer composite use increased	13
Plastics use increased	6
Adhesives	4
Lighter weight materials	3
Magnesium	3
Advanced "skin" composites for crashworthiness; Alternative materials; Composites—lighter weight; Light metals replace plastic; New materials and associated manufacturing processes; Paints—low emission; Plastic body panels; Plastics—improved; SMC and similar	1% each
Structure/design	**14%**
Space frame construction	5%
Aerodynamics	4
Cab forward; De-couple mass and stiffness; Improved FEA to optimize body construction; Structural integrity and efficiency increased; Structure to reduce noise	1% each
Manufacturing/assembly	**4%**
Flexible manufacturing	3%
Production measurement for improved fit	1
Other	**16%**
Recyclable plastics /composites	5%
Quiet emphasis	4
Fiber optic or low cost video alternative to rearview mirrors; Interior more friendly; New construction techniques; New seat construction and methods of assembly/manufacturing; Pre-painted sheet; Safety emphasis; Weight reduction	1% each

Discussion—Body

The largest response for new technology in the body area is with respect to materials. Specifically, aluminum, polymer composites and plastics are the most frequently mentioned. The application of these materials is addressed further in TECH-44 for the total vehicle and TECH-45 for specific exterior body components. Significant increases in the use of these materials is forecast by 2003 in both of these questions. Recyclability is an area related to materials which will receive increased attention in the future. Recyclability may have a significant influence on the materials used in the next decade. For additional information on this issue, see questions TECH-50 and TECH-51.

Chassis	Percent of Responses
Materials	**22%**
Aluminum	10%
Composite materials	8
ER fluid dampers	3
Magnesium	1
Brakes	**13%**
ABS	6%
All electrical brakes; Brake lining compounds—new; Brake-by-wire; Brakes—smaller; Radar braking; Regenerative braking for electric vehicles; Steer and brake-by-wire	1% each
Suspensions	**13%**
Active suspension	8%
Semi-active suspension	4
Smarter suspensions	1
Electrical/electronic	**9%**
Fuzzy logic/neural networks	3%
Integrated chassis controls	3
Computerization of subsystems; Electric power steering; Electronics—low cost	1% each
Other	**11%**
Weight reduction	6
Merger of body and chassis for more integrated control system; Micro-machined sensors/actuators; Standard databases; Traction control; Variable trim height with speed—fuel economy	1% each

Discussion—Chassis

Most frequent responses for new chassis technology relate to materials—specifically aluminum and composite materials—active suspensions, and ABS brakes. Additional detail related to ABS brakes is included in TECH-59.

Active suspensions are covered in more detail in TECH-57, where only 3 percent penetration is forecast for 2003. The disparity between the number of panelists listing active suspensions as a new technology that will have a significant impact in the next decade in this question and the low percent penetration noted in TECH-57 may be a result of the technical appeal associated with this system. It is difficult for engineers not to be enthused about the possibility of a new high-tech technology, but selling this technology to the public at a price that they are willing or able to pay is a different matter.

Electrical	Percent of Responses
Systems advances	**51%**
Multiplexing	23%
Fiber optic systems	16
Central system; Computer integration; Controls logic advances; Databases standard; drive-by-wire systems; Electrical load management to improve efficiency; Electrical systems more efficient; Personal computer like EE logic and control systems; Protocol—standardize systems; Signal processing; Significantly higher throughput and memory controls—maybe even affordable parallel processor; Up-integration increased	1% each
Components	**20%**
Connectors—more reliable and accepted bus standard for multiplexing; Electronics for control; Electronics—lower cost; High intensity discharge lighting	3% each
32-bit microprocessors; DSP controllers—low cost; Integrated ECU for engine/transmission; LCD color flat screens; Motors—smaller, more powerful; Relays—solid state; Sensors—low cost; Wiring—lighter	1% each
Higher system voltage	**9%**
Higher voltage systems	5%
24-volt system	3
12/48 volt systems	1
Accessories	**6%**
Alternators—higher speed, more efficient	3%
Alternators—high amperage; Electrical steering; Lighting systems—low power single source—interior and exterior	1% each

Discussion—Electrical

The two areas receiving the most responses for new electrical technology are multiplexing and fiber optic systems. Projected use of multiplexing by 1998 and 2003 is addressed in TECH-95. The use of fiber optics in multiplexing is addressed in TECH-96.

Safety	Percent of Responses
Passive restraints	**30%**
Airbags—front and side	12%
Airbags—front and rear standard	8
Airbags—standard double	8
Airbags—next generation; Automatic passenger encapsulation	1% each
Monitoring devices	**25%**
Collision avoidance	13%
IVHS	6
Cruise control—intelligent	3
Driver performance/condition monitoring—non-contact; Blind spot detection; Tire pressure monitoring devices	1% each
ABS	**12%**
ABS standard	12%
Structure design	**7%**
Body structure design for safety	3%
Crush space; Honeycomb type materials; Material—new; Seat structures—improved	1% each
Lighting/vision:	**3%**
IR for night vision; Lighting schemes—interactive for interior safety; UV headlights	1% each
Restraints	**3%**
Belts—4 point; Restraints—improved, automatic; Restraints—side and rear impact	1% each
Other	**12%**
Side impact	3%
Active safety; Active suspension; Engine and chassis—increased control for accident avoidance; Fuel shut-off devices; Heads-up display; On-board extinguisher systems; On-board vehicle recorders; Rollover protection; Traction control	1% each

Discussion—Safety

The most frequent responses for new safety technology are for airbags, ABS and IVHS systems. Application rates for airbags is summarized in TECH-62, ABS in TECH-59, and IVHS systems in TECH-64.

Comfort/Convenience	Percent of Responses
Convenience	**30%**
Navigation—electronic	13%
Human factors—more attention	5
Windshield wipers—rain sensing	3
Cruise control—smart; Integrated CRT/head-up/steering wheel controls; Memory systems—personalized; Mirrors—improved auto-chromatic; Personalization of comfort and convenience by driver I.D. (i.e., radio, climate control, seating, etc.); Radio—Digital readout; Service monitors; Voice activated controls; Voice recognition	1% each
Comfort	**11%**
Noise—active cancellation	5%
Climate control systems more efficient; Glare shields improved; Noise control; Seats—automatic positioning relative to steering wheel, pedals, etc.; Seats—individually contoured; Seats—multi-adjustable	1% each
New content	**11%**
Communication systems built in (cellular phones, fax, modems)	4%
Phones—built in, voice activated, handsfree	3
Audio/visual—high content; Radio—data; Remote mirrors (not external); Yellow Pages display	1% each
Safety	**5%**
IVHS	4%
Distance detectors—sonic	1
Other	**3%**
Electronics	2%
Light systems—fiber optic	1

Discussion—Comfort/convenience

The most frequent response for new comfort/convenience technology is for electronic navigation. The projected application rate for these systems is summarized in TECH-64.

As quality, fuel economy and other parameters approach parity for the manufacturers, comfort and convenience may well be the discriminators that drive the purchase decision. There are many examples in the recent past where manufacturers provided technology for technology's sake, only to have it rejected by the customer. The manufacturer that can determine where new technology will be a true benefit to the customer, and apply that technology in an effective manner with high quality at a reasonable cost, will have an advantage in the marketplace.

Glass	Percent of Responses
Solar control	**22%**
Active tinting in bright light	12%
Solar treatments—low cost	5
100% UV proof	3
Electrochromatic glass; High reflective	1% each
Material changes	**13%**
Plastic windows	8%
Lightweight—polycarbonate or lexan	5
Reliability, durability	**4%**
Bonding and attachment techniques improved	3%
Damage resistance improved	1
Other	**12%**
Computerized warming, self-defrosting	3%
Water repellent coatings—long lasting	3
Complex shaping; Glare reduced; Message schemes embedded in glass; Mirrors auto dimming; One-touch-up control of side windows; Sensor- activated wiping	1% each

Discussion—Glass

Most frequent responses for new glass technology are for active tinting, plastic windows (polycarbonate or Lexan) and low-cost solar treatments. The application rate for active tinting is addressed in TECH-41.

Strategic considerations

Again, we see a huge potpourri of ideas and technologies suggested. In our opinion, a question of this type should be examined carefully, since even a single response from someone who knows something unique could have a profound product impact over time.

Another related point is that the definition of a new technology is highly sensitive to personal perspective. Many technologies suggested are, in fact, now being implemented in some form or another.

It is worthy noting that electronics cuts across many of the systems. This makes systems integration a key requirement in the design process.

Information on all of these technologies is key to successful and timely execution in the vehicle. Information required includes level of value-added, (including cost, customer satisfaction, etc.), barriers (technology, investment, etc.) and who is leading in implementation.

Finally, it should be noted that any technology is essentially worthless when poorly executed or of no value to the customer.

TECH-40 What new uses for computers do you anticipate in the design or manufacturing process by 2003?

Summary of responses

Design

- CAD/CAE/CAM total integration will become computerized.
- Computers will be used in analytical prototyping.
- Computers will handle individual control of all engine function at each cylinder.
- Design networks—designing and processing the product—will become more computerized.
- Digital mock-ups will become commonplace.
- Durability evaluation will be done by computers.
- FEA of all car components and their tolerencing will be calculated.
- Prototype circuit boards direct from CAD to emitted code in one hour will be possible.
- Rapid prototyping techniques could develop rapidly into one-off or small-run production part processing.
- Requirements allocations and balancing will become an upfront computer analysis before design is started.
- They will be used for auto-documentation and databases with less paper.
- They will be used for complete vehicle packaging and process layout and process sheets.
- They will become more prevelent for data base management along with total simulation in the design and development process.
- We will see them in CAE from simulated design to prototype hardware.
- We will use computers to design more user-friendly tools.

Modeling/simulation/Verification

- Complete auto system simulation of hardware and software will be possible.
- Computers will help with integrated vehicle dynamics.
- Computers will simulate the assembly line at engineering stations, product verification, combustion, aero, crash and vehicle sub-systems with design feedback.
- Fluid dynamics CAD software for better component aero (brakes, manifolds, air conditioning, heat, coolant flow, oil flow) will be common.
- Reliability modeling and sensitivity to variation will replace much testing, but we cannot test to future reliability requirements.
- They will be used in fluid dynamics computation for autodynamics and NVH refinement
- User-friendly models for tires, suspension, and vibration will be computer-based.
- We will see computerized ride metrics and development of ride/handling packages tailored to market segment preferences. Road tests will be conducted only to confirm results.
- We will see control algorithms modeling, including sensors and actuators.

Manufacturing/Assembly

- Analytical S/M tool development and formability will increase.
- Computer terminals on the factory floor will provide current product information and all manufacturing methods for each part.
- Electronic diagnostics at assembly line station will increase.
- I expect complete on-line quality monitors built into production systems with closed loop quality control features.

Sales/Service/Marketing

- Marketing feedback will be facilitated.
- Order processing within three to five working days will be typical.

Miscellaneous

- Archetyping will be much more computerized.
- Bar code scanning will be the norm.
- Better database access for warranty/service/test will occur.
- I expect significant progress in data exchange.
- More user-friendly applications will evolve.
- Software development will be automated from high-level design.

Discussion

Many changes are forecast to take place in the use of computers in the next decade. This is not surprising, looking at the recent past, and it is likely that many changes that will take place in the next five years are not on this list because they have not been thought of yet.

As noted in TECH-35, many of the uses for computers mentioned are not new but rather advances, increases or improvements on current uses.

Manufacturer/supplier comparison

These 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

The myriad new uses for the computer noted must be used in the most appropriate way to maximize the value-added in terms of time, quality and cost. This includes uses in design, manufacturing, sales and service. Appropriate application and software may be as important as new hardware. The organization that utilizes available computer technology to its advantage will have an advantage over the competition.

TECH-41 What percent of glass will include active tinting or be electrochromatic by MY 2003?

Glass Area	MY 2003	
	Median Response	Interquartile Range
Windshield	10%	5/20%
Other glass	5	2/15

Selected edited comments

- Half of all review mirrors will use active tinting by 2003.
- Less safety critical applications like sunroofs/moonroofs will lead the rollout of active glass.
- This will be an option on luxury vehicles only. Too many more fundamental problems face the industry to spend much time on this.
- Who will pay for all of these new features?
- Widespread application requires a reversal whereby energy is added to make dark versus clear as a failure mode consideration.

Discussion

The application rate of active tinting or electrochromatic glass by 2003 is forecast to be quite low, at 5-10 percent.

Manufacturer/supplier comparison

Manufacturers' and suppliers' median responses for windshields are 15 percent and 10 percent respectively. The two are in agreement for other glass.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

As in many other new features or technologies, a major concern is cost and perceived customer value. The failure mode issue raised in the comments may also be a significant limiting factor. If this is solved, luxury vehicles may see some application.

TECH-42 Chrysler Corporation recently introduced a "cab forward" styling theme in the midsized passenger car market. What percentage of North American-produced passenger cars do you expect to follow this theme by 2003?

Cab forward percentage by 2003	Median Response	Interquartile Range
	50%	25/65%

Selected edited comments

- Cab forward will be replaced by something else by 2000.
- Increased passenger room will necessitate going to this design concept.
- Modern concepts always flow across the business.
- Other car companies already had cab forward styling but did not take advantage of the marketing.
- True cab forward (Chrysler LH is more "base of windshield" forward) is a future trend.

Discussion

Cab forward is a styling theme that moves the front wheels and windshield forward in the vehicle. Panelists forecast a 50 percent penetration of the cab-forward design by 2003. The technical advantages and disadvantages of this theme are summarized in TECH-43.

The skewed interquartile range may indicate that there is disagreement between manufacturers regarding the definition of cab forward.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

It is most likely that cab forward will be applied to totally new platforms as opposed to re-skins of current platforms because of the significant investment required to make this change. Obviously, the response of the ultimate customer who is today preoccupied with value—getting the most for the least cost—is a critical consideration. The advantage of maximizing interior volume would appear to be a particularly positive value factor. This design theme will indeed be interesting to watch in the next several years. Also, the comment above related to marketing should be carefully noted. Some in the industry are far better than others in communicating product features to customers.

A design theme advantage may give a manufacturer a competitive advantage for a longer period of time than a technology advantage because of less frequent major design changes and the major capital expense associated with these changes.

TECH-43 What do you believe are the advantages and/or disadvantages of "cab forward" styling? Please consider both the manufacturers' and the customers' perspectives.

Advantages:	Percent of panelists
Space utilization:	**54%**
Interior roominess	48%
Trunk capacity improved	5
Leg room improved	1
Styling/customer perception:	**27%**
Styling	25%
Customer perception; Uniqueness	1% each
Ride/Handling:	**10%**
Handling improved (wheels to the corner)	5%
Ride improved	4
Mass distribution improved	1
Visibility	**7%**
Visibility	7%
Other:	**5%**
Manufacturing flexibility; N/V characteristics improved; None apparent; Not a big deal; Safety	1% each
Aerodynamics	**8%**
Aerodynamics improved—CAFE	8%

Disadvantages:	Percent of panelists
Engine compartment	**46%**
Engine packaging, accessibility for service	33%
Thermal management underhood	13
Large windshield	**27%**
Sun load (cooling)	17%
Deep dash	3
Hard to clear/clean	3
High replacement cost; Increased glass mass; Performance reduced—mass increased; Positioning of driver to windshield unnatural	1% each
Safety	**12%**
Front crush space—safety	11%
Perceived safety	1
Other	**11%**
Glare on instrument panel; Noise increased; Visibility	3% each
Aerodynamics—increased track; Driveline efficiency; Handling problems; Increased turning circle; Mass on front wheels increased; May limit development of distinctive models off the platform; Not aware of any; Styling	1% each

Discussion

Advantages most frequently mentioned for cab forward are interior space utilization and styling/customer perception. Disadvantages most frequently noted are engine compartment congestion and a large windshield. The issue of underhood thermal management is addressed in TECH-105. Please note respondents' individual comments regarding the potential disadvantages of a large windshield.

One respondent notes increased mass on the front wheels as a disadvantage. This is a significant consideration for a re-skin where the front wheels and windshield are moved forward with no other compensating changes to the vehicle. In a new design such as Chrysler has introduced, however, some significant design changes can be accomplished. Specifically, by utilizing a fore-aft engine orientation and locating the center of mass of the transmission well behind the drive axles, it is possible to maintain a reasonable front/rear weight distribution.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

Styling is one of the few vehicle attributes that sets one vehicle apart from others in today's marketplace. Chrysler has taken a styling theme, addressed the technical issues, and produced a winner. It is likely that others will move in this direction as well. Capital investment to make changes to the extent of those undertaken by Chrysler are significant, however, and will likely come only at the time of introduction of a new platform or model. The customer will certainly be the final voice in cab forward's success or failure. All indicators today suggest it will be a solid success for Chrysler, but the outcome is less certain for other manufacturers.

TECH-44. Please forecast the materials content, in pounds, for the average North American-produced passenger car for MYs 1998 and 2003 given the indicated CAFE scenarios. Leave blank any materials with which you are unfamiliar.

Materials	Est. 1990*	Median Response			Interquartile Range		
		1998 27.5 mpg	1998 30 mpg	2003 35 mpg	1998 27.5 mpg	1998 30 mpg	2003 35 mpg
Steel	1716.5	1650 lbs	1550 lbs	1400 lbs	1600/1700	1500/1647	1300/1500
Cast iron	454	420	380	320	40/450	300/400	250/380
Aluminum	158.5	175	200	250	165/200	180/250	200/300
Plastics/Composites	229	250	270	300	240/252	250/300	270/330
Copper	48.5	48	45	40	45/50	41/50	38/48
Zinc (include coatings)	18.5	18	17	16	17/19	15/19	10/19
Magnesium	4.5	5	10	15	5/10	6/15	8/25
Glass	86.5	86.5	85	80	85/90	80/90	70/88
Powdered Metals	24	25	26	28	24/26	24/30	25/35
Rubber (including tires)	136.5	135	135	130	135/137	130/136	125/136

* **Source:** *Ward's Automotive Yearbook,* 1992.

Selected edited comments

- Aluminum, plastics and magnesium use will grow as CAFE increases.
- Copper will be reduced by multiplexed fiber optics by 2003.
- For 1997 to 1998, the basic architecture of the cars is defined. There will be little change in content.
- Usage of aluminum will increase not only for weight reduction but also because of its ability to be recycled—therefore gaining percentage-wise compared to plastics.
- We will see significant use of magnesium and aluminum.

Discussion

As in the previous Delphi surveys, panelists forecast a trend away from high-weight materials to lower-weight materials. Specifically, significant reductions in steel and cast iron are indicated, along with significant increases in the uses of aluminum and plastics/composites across the fuel economy scenarios.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Comparison of forecast: MAT-15

In the materials survey, panelists were asked to forecast a percentage change for each material from a 1990 base. Results of the technology and the materials surveys are presented in the following table.

Materials Content	Est. 1990	Median Response					
		1998 27.5 mpg		1998 30 mpg		2003 35 mpg	
		TECH	MAT	TECH	MAT	TECH	MAT
Steel	1716.5	1650	1699	1550	1631	1400	1562
Cast iron	454	420	430	380	409	320	386
Aluminum	158.5	175	174	200	182	250	190
Plastics/composites	229	250	240	270	252	300	263
Copper	48.5	48	48	45	48	40	48
Zinc	18.5	18	19	17	18	16	18
Magnesium	4.5	5	4.5	10	4.5	15	4.5
Glass	86.5	86.5	86.5	85	86.5	80	86.5
Powdered metals	24	25	25	26	25	28	26
Rubber	136.5	135	136.5	135	136.5	130	136.5

Panelists in the technology survey forecast larger decreases in steel and cast iron and a larger increase in aluminum, plastics/composites and magnesium as compared to Delphi materials panelists. The difference between panelists may be due to the fact that materials panelists are closer to the changes in the past and are more cautious regarding dramatic shifts in materials usages for the future. Another factor may be the manner in which the question was asked. Specifically, technology panelists were asked to specify their estimate in pounds whereas materials panelists specified changes from a baseline on a percentage basis.

Trend from previous Delphi surveys

Estimates for all materials and fuel economy scenarios are within 5 percent for the 1992 Delphi VI survey and the current survey with the following exceptions:

Materials	1992 Delphi VI			1994 Delphi VII		
	1995		2000	1998		2003
	27.5 mpg	30 mpg	35 mpg	27.5 mpg	30 mpg	35 mpg
Aluminum - lbs.	190	—	215	175	—	250
Magnesium - lbs.	—	6	8	—	10	15

Panelists in the current survey forecast a lower use of aluminum in the short term but significantly larger use of aluminum in the long term as compared to the 1992 Delphi VI study.

On a percentage basis, the current panelists forecast a substantially higher use of magnesium than did 1992 Delphi VI panelists, although the difference in pounds is not great.

Strategic considerations

Any meaningful deviations from the projected fuel economy standards will affect the utilization of lightweight materials because of their higher relative cost and unique assembly requirements for body components. The trade-off between cost, weight and function will continue to receive much attention in the next decade. In fact, much more comprehensive system-based value analysis is on the horizon which should help engineers with material selection decisions.

Recyclability is another factor that will influence the use of various materials. This aspect is covered in more detail in TECH-50 and TECH-51. Materials such as aluminum which are relatively easily recycled may see wider use than perhaps plastics/composites which are somewhat more difficult to recycle. Ultimately, the recyclability of the material will factor into the life-cycle cost of the material. Because of the enormous material mass consumed by the auto industry, even small changes can affect supply/demand and therefore cost/availability matters. For the automotive industry to increase use of any material, it needs to be assured there is adequate and secure supply projected over the long term.

An additional factor influencing material selection is the progress being made with traditional materials. The intense competition is prompting the more traditional material suppliers to develop new products and processing technology. Consequently, any new material is facing a fast-moving target. We continue to believe that the automotive material competition will expand and represent one of the key battles of the coming decade. If you are in the material business, fasten your seatbelt.

TECH-45 Consider these automotive exterior components. For each component, indicate the percentage of North American production that will be steel, plastic or aluminum.

1998 Passenger Car	Median Response			Interquartile Range		
	Steel	Plastic	Aluminum	Steel	Plastic	Aluminum
Automotive Components						
Hood (exterior)	80%	10%	10%	80/85%	5/10%	8/15%
Roof	95	3	2	90/95	1/5	1/5
Doors	89	8	5	85/90	5/10	2/5
Rear deck	85	10	5	80/85	6/10	5/10
Front fenders	85	10	5	80/85	8/12	5/7
Rear quarter panels	90	5	5	85/90	5/10	2/5

2003 Passenger Car	Median Response			Interquartile Range		
	Steel	Plastic	Aluminum	Steel	Plastic	Aluminum
Automotive Components						
Hood (exterior)	70%	15%	15%	65/75%	10/20%	10/20%
Roof	85	5	5	80/90	5/10	5/10
Doors	75	15	10	70/80	10/15	5/15
Rear deck	70	15	15	60/75	10/20	10/20
Front fenders	70	20	10	65/75	10/25	5/15
Rear quarter panels	80	14	7	70/85	10/15	5/10

***Note**: base line numbers were not provided.*

Selected edited comments

- Aluminum will continue to be too expensive.
- CAFE and recyclability are the big factors, especially for plastic body parts.
- Composite materials will see a sharp drop in cost of materials and fabrication.
- The figures depend on CAFE.
- Higher cost and quality concerns are holding back use of aluminum/plastics for exterior panels.
- Little change in material mix will occur until designers start with alternate material characteristics instead of the 30-year practice of designing in steel and then try thinking to substitute another material when a goal such as weight or cost is not met.
- Mass savings of plastics is severely compromised by reinforcements. I do not expect major growth in plastic fenders.
- Plastic has a weight disadvantage but a corrosion advantage.
- Quality expectations or today will make aluminum very expensive due to excess scrap.
- Repair costs and integrity of welds is a major problem for aluminum. It may be solved. Plastic will only be used for skin (in high volume).
- Roof and doors need steel's strength for crashworthiness.

Discussion

The use of aluminum and plastic for exterior body components is expected to increase substantially in the next decade, but steel should remain the dominant material.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement in all areas, except those shown below.

Passenger Car Automotive Components	Plastic - 2003	
	Manufacturer	Supplier
Front fenders	15%	25%
Rear quarter panels	10	15

Trend from previous Delphi surveys

This question was asked in previous surveys, but aluminum was first addressed in the 1992 Delphi VI survey. Comparisons with previous Delphi forecasts for steel, plastic, and aluminum are summarized in the following tables and graphs. Since the forecast years are different in the 1994 Delphi VII than previous surveys, tabular comparisons are presented for the past surveys, and some selected components are compared to the present survey.

Automotive Components	Forecast for 1995 Percent of North American Produced Passenger Vehicles						
	Steel			Plastic			Aluminum
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VI (1992)
Hood (exterior)	70%	90%	88%	30%	10%	10%	2%
Roof	85	95	94	15	5	5	1
Doors	75	95	94	25	5	5	1
Rear deck	60	90	88	40	10	10	2
Front fenders	67	90	89	33	10	10	1
Rear quarter panels	70	95	94	30	5	5	1

Automotive Components	Forecast for 2000 Percent of North American Produced Passenger Vehicles				
	Steel		Plastic		Aluminum
	Delphi V (1989)	Delphi VI (1992)	Delphi V (1989)	Delphi VI (1992)	Delphi VI (1992)
Hood (exterior)	85%	78%	15%	15%	7%
Roof	95	90	5	8	2
Doors	90	85	10	10	5
Rear deck	85	80	15	15	5
Front fenders	80	80	20	15	5
Rear quarter panels	90	85	10	10	5

The forecast for the use of aluminum in the 1992 Delphi VI for 2000 is quite similar to the current forecast for 1998, but substantially below current forecasts for 2003.

Automotive Components	1995			1998	2000		2003
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1993)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Plastic Hoods	30%	10%	10%	10%	15%	15%	15%
Plastic Front Fenders	33%	10%	10%	10%	20%	15%	20%

The above table shows that the forecast for use of plastic hoods has declined with each Delphi.

The forecast for the use of plastic in front fenders has been relatively consistent in the last three surveys but shows a marked reduction from the 1987 Delphi IV forecast of 33 percent in 1995.

Strategic considerations

Panelists forecast substantial use of plastic and aluminum in body panels by 2003. This shift would have a major impact on the suppliers of these materials, as well as the suppliers of steel, assembly operations and body shop repair. As discussed in TECH-44, however, the fulfillment of this forecast is highly dependent on recycling issues and the level of fuel economy standards. Aluminum and plastic currently are more expensive than steel, and only at the system level can effective decisions be made. Plastic is more difficult to recycle than steel. Aluminum appears to be less dent resistant and more difficult to assemble than steel.

A number of applications of plastic body panels in the industry have provided production experience and confidence in the technology. These applications include the Saturn, GM APV and Chrysler LH. The GM APV is built on an earlier, heavier space frame and is all plastic on exterior panels. The Saturn and Chrysler LH use plastic side panels only.

The Honda NSX and other selected products are providing real world production experience with aluminum body panels. All manufacturers have programs aimed at the development of the application of this lightweight material. One European manufacturer claims that it will introduce an all aluminum body vehicle in 1994. Of the myriad of material competitions, those in the body exterior are particularly noteworthy. Obviously, the stakes are enormous. Future regulations will have an impact on selection as will economics, customer demand and a host of other factors. The better the industry becomes at applying true systems engineering, the more cost effective the decisions will be. The statement in the comment section with regard to simply substituting light weight materials for steel without better systems engineering is particularly important. It is also particularly important today to recognize customers are extremely sensitive to value and affordability.

TECH-46 What percentage of gasoline-fueled North American-produced passenger cars will have gas tanks made from steel, plastics or aluminum in the indicated years?

Gas Tank Materials	Median Response		Interquartile Range	
	1998	2003	1998	2003
Steel	80%	60%	75/85%	50/70%
Plastic-based materials	20	40	15/25	30/50
Aluminum	0	0	0/0	0/1

Selected edited comments

- Evaporation standards will drive us to steel unless permeability issues are resolved.
- New barrier technologies may increase the number of plastic tanks, but permeability and cost remain issues.
- Plastic is not currently legal in Europe.
- Plastic is too costly—will be used when packaging/safety issues are compelling.
- Plastic materials will be developed that will be less permeable and more resistant to fires.
- Plastic will increase for safety, fuel volume and lower mass.
- Use of aluminum will probably be avoided since it is attacked by alcohol-containing fuels, and use of these fuels is increasing.
- Weight and size reduction implies more complex shapes to attain volume. Plastics are better suited for this.

Discussion

Steel is expected to remain the dominant material for fuel tanks in the next decade, although plastic-based materials are likely to become more prevalent, according to our panelists. This indicates that issues such as permeability will be satisfactorily resolved. The relatively large interquartile range for plastics indicates some uncertainty and/or different strategies in this area, however.

Aluminum is not expected to see significant application in fuel tanks because of possible safety issues and its vulnerability to alcohol. As in most areas of the vehicle, technology should be monitored closely since a critical breakthrough could significantly alter these forecasts.

Manufacturer/supplier comparison

The manufacturer and supplier are in general agreement.

Comparison of forecast: MAT-26

Technology and materials panelists are in agreement for 2003. For 1998, results are shown in the following table.

Gas Tank Materials	1998 Median Response	
	TECH	MAT
Steel	80%	70%
Plastic based material	20	30

Trend from previous Delphi surveys

This question was asked for the first time in the 1992 Delphi VI survey. The results are in close agreement with the current survey.

Strategic considerations

The move from steel stampings to plastic-based materials may have a significant impact on suppliers and on tools required.

TECH-47 What percentage of alcohol-fueled North American-produced passenger cars will use the following fuel tank materials by MYs 1998 and 2003?

Alcohol-Fueled Gas Tank Materials	Median Response		Interquartile Range	
	1998	2003	1998	2003
Stainless steel	20%	10%	10/50%	5/20%
Coated low carbon steel	30	20	25/70	15/50
Plastic-based materials	20	50	15/33	25/70

Selected edited comment

- An aluminum or plastic tank with bladder insert will reach zero percent in 1998 and 20 percent in 2003.

Discussion

The fuel tank material for alcohol-fueled vehicles in the next decade is not clear, although plastic-based materials received the highest median response in this survey. The large interquartile range indicates significant uncertainty or disagreement between panelists regarding this issue.

The number of alcohol-fueled vehicles is not expected to be large for the foreseeable future. The long-term durability of coated low carbon steels and plastic-based materials with alcohol is yet to be proven, but the cost incentive compared to stainless steel is great.

Manufacturer/supplier comparison

The manufacturer and supplier are in agreement.

Comparison of Forecast: MAT-27

Forecasts for technology and materials surveys are in general agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey for 2000. The results are summarized below.

Fuel Tank Material for Alcohol-Fueled Vehicles	Median Response		Interquartile Range	
	2000	2003	2000	2003
	Delphi VI (1992)	Delphi VII (1994)	Delphi VI (1992)	Delphi VII (1994)
Stainless steel	30%	10%	10/85%	5/20%
Coated low carbon steel	20	20	9/40	15/50
Polymer-based materials	10	50	5/60	25/70

Strategic considerations

The statements from the previous question regarding impact on tooling and suppliers apply here also. However, since the number of vehicles using alcohol is likely to be limited, the impact on suppliers may be small.

TECH-48 What percentage change in total vehicle weight do you anticipate by 1998 and 2003? Please indicate plus or minus.

	Median Response		Interquartile Range	
Total Vehicle Weight	1998	2003	1998	2003
Percentage Change:	-3%	-8%	-5/5%	-15/10%

Selected edited comments

- Additional content (safety, convenience, etc.) will offset mass reduction in the short term.
- At issue is crashworthiness versus mpg. Downsized/lighter vehicles appear less safe.
- Average weight will come down partly because of mix shift to smaller cars.
- Increased features/functions will offset weight savings of materials, etc. in 1998.
- Weight change will be primarily due to plastics and aluminum.

Discussion

The panel forecast a reduction in total vehicle weight for 1998 and 2003, but there is considerable uncertainty as evidenced by broad interquartile ranges.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement.

Comparison of forecast: MAT-13

Technology and materials panelists are in agreement on this question.

Trend from previous Delphi surveys

This question was asked as a part of the material content question in the 1992 Delphi VI survey. The results are summarized below.

	1995		2000
1992 Delphi VI Summary	27.5 mpg	30 mpg	35 mpg
Percent change from 1990 Est.	-4.6%	-5.9%	-11.4%

The forecast decreases in vehicle weight are somewhat smaller in the near term and somewhat larger in the longer term in the current survey than they were in the 1992 Delphi VI survey.

Strategic considerations

As noted in TECH-2, the continued customer demand for large vehicles with low relative fuel prices will limit the weight reduction economically feasible in the near future. It should also be noted that the interquartile range of forecast weight change in this survey encompasses both a weight loss and a weight gain in the 1998 and 2003 timeframe. There is no consensus among the panelists with regard to the net effect of lighter weight materials, potential downsizing, and the increased content required by the customer and more stringent emission and safety standards. The relatively broad interquartile range may indicate uncertainty based on a variety of unknowns or different product and market strategies. Furthermore, a factor in weight reduction expectations may be increased ability to improve fuel economy through other means such as powertrain or tires.

TECH-49 Assuming CAFE requirements at 27.5 mpg in 1998 and 30 and 35 mpg in 2003, what is the value, today in current dollars, per pound of weight saved to a vehicle manufacturer? What will it be in 1998 and 2003? Please do not adjust for inflation.

Median Response				Interquartile Range			
1993 27.5 mpg	1998 27.5 mpg	2003 30 mpg	2003 35 mpg	1993 27.5 mpg	1998 27.5 mpg	2003 30 mpg	2003 35 mpg
$2.00	$2.00	$3.00	$4.00	$1.50/2.00	$1.50/2.00	$2.00/3.00	$3.00/4.75

Selected edited comments

- Continued use of weight reduction as a CAFE improving criteria will become too expensive.
- The bottom line will continue to be price, not weight savings.
- The mass reduction trade off value will increase over time and become a bonafide driver in sourcing decisions.
- This assumes fuel cost stays relatively constant.

Discussion

The value of a pound of weight saved in a vehicle is forecast to escalate dramatically in the next decade. This increased value is in response to expected increased CAFE requirements. Substantial cost increases are anticipated to meet CAFE requirements based on this forecast.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement.

Comparison of forecast: MAT-14

In the Materials survey, the question is asked in two parts. The first asks the value to meet general CAFE requirements. The second asks the value to meet a specific EPA weight class. The expected values for CAFE are not stated. The materials panelists place a significantly lower current value on a pound of weight savings compared to technology panelists. Results of the materials survey are summarized below.

Value of a Pound of Weight Savings—Materials Forecast			
Weight Reduction Objective	Current Value	1998	2003
Meet CAFE requirements	$1.00	$1.75	$2.50
Meet specific EPA weight class	1.00	2.00	3.00

Trend from previous Delphi surveys

This question was asked in early Delphi forecasts, but was omitted in those released in 1987 and 1989. Results in the following table have been adjusted to 1993 dollars. CAFE values were not given in the 1992 survey.

1992 Delphi VI and 1994 Delphi VII Comparison (1993 Dollars)							
	1991	1993 27.5 mpg	1995	1998 27.5 mpg	1998 30 mpg	2000	2003 35 mpg
1994 Delphi VII	—	$2.00	—	$2.00	$3.00	—	$4.00
1992 Delphi VI	$1.06	—	$2.12	—	—	$3.18	—

Results for Delphi VI and Delphi VII are comparable.

Strategic considerations

There will likely be large increases in vehicle cost to meet the anticipated CAFE requirements. This could have implications for total vehicle sales, as sales volume is reasonably dependent on vehicle price.

The value of a pound of material saved will vary depending on how the manufacturers comply with CAFE. The tendency will be to drive up prices for manufacturers of primarily large vehicles because of their greater need for improved fuel economy. This could give manufacturers of "on average" smaller vehicles a large financial advantage, as they would be able to move upscale to a larger and more profitable vehicle segment without the cost penalty of weight reduction.

The option of reducing vehicle weight to meet CAFE will be balanced carefully against other alternatives such as developing more efficient powertrains, controlling model mix or reducing performance. Today, customers are extremely concerned about affordability and value, and must be treated carefully with regard to any factor that could lead to significant price increases. Other value-oriented factors such as safety must also be considered.

Again we should state that true system level analysis is necessary to deal with this issue. Also, when we look over a long period of time (1981 Delphi II and 1984 Delphi III) it is remarkable how efficiently (low cost per pound) the industry has dealt with this issue.

TECH-50 The recyclability of automotive materials and related environmental concerns are significant issues confronting the auto industry, including both OEMs and suppliers. Please rank on a scale of 1 to 5 where 1 = extremely important and 5 = not at all important, the significance of the following potential barriers to the recycling of each of the materials categories.

Potential Barriers	Ferrous metals	Nonferrous Metals	Plastics/Polymers		Fluids
			Thermoplastics	Thermosets	
Recycling infrastructure	4.1	3.6	2.4	2.1	2.6
Cost of reclamation/recycling	3.7	3.2	2.1	1.6	2.2
Labeling/ identification	4.0	3.4	2.5	2.4	2.6
Ease of materials separation	3.7	3.0	2.1	2.0	2.6
Development of market/uses for recovered parts and materials	4.1	4.0	2.5	1.9	2.1

Other responses include:
There is a lack of incentive to bring dead cars in, an extremely important issue for all categories.

Selected edited comments

- The federal government needs to add incentives (economic and regulatory) to accelerate and maximize recycling.
- The infrastructure, separation technology, marketing exist abroad for metals. They are important, but are not barriers. Cost could be a barrier if the economics change.

Discussion

Panelists rate the barriers to recycling of ferrous metals as being of minor significance; nonferrous metals as somewhat important; thermoplastics and thermoset polymers as quite important; and automotive fluids as somewhat to quite important, depending on the compound.

Manufacturer/supplier comparison

Manufacturers and suppliers results agree within 0.5 rating points in all areas with the exception of labeling/identification of fluids, where manufacturers rated 2.9 versus 2.1 for suppliers.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey. Fluids were added in this survey. The list of potential barriers was revised, ferrous metals were combined, and unreinforced and reinforced thermoplastics were combined in this survey. The areas that were combined have been averaged in the following table. The barriers that were common between the two surveys are summarized below for the 1992 Delphi VI survey.

Potential Barriers	Ferrous Metals	Nonferrous Metals	Plastics/Polymers	
			Thermoplastics	Thermosets
Recycling infrastructure	3.4	3.2	1.9	1.7
Cost of reclamation/recycling	2.9	2.8	2.1	1.7
Labeling/identification	2.9	3.8	2.1	2.2
Ease of materials separation	3.3	2.9	2.1	2.0
Development of market/uses for recovered parts and materials	3.8	3.6	2.5	1.9

Panelists in the current survey rate the barriers to recycling ferrous and nonferrous metals as somewhat less important than did panelists in the 1992 Delphi VI survey. Results for plastics/polymers are very similar between the two surveys.

Strategic considerations

Recycling is an issue that has received much attention and legislative action in Europe. It is likely that this trend will occur in North America as well. Manufacturers will likely have to use a true life cycle analysis of materials, including recycling, in the selection of materials. This will create many new challenges for the automotive industry and will be reflected in the design and manufacture of many automotive components. Suppliers must be aware of this issue because it may significantly change the cost/benefit ratio of current materials and precipitate material changes.

Many new opportunities will become available, however, to those that take the initiative to develop methods, procedures and equipment to facilitate recycling. It is imperative for the industry to lead regulation on this issue—to become proactive. There is an excellent opportunity to participate in future rulemaking by taking positive action. Design and manufacture for recycling appears to be an inevitable trend, and it is better to lead rather than to follow.

TECH-51 Do you expect federal or state level government regulatory activity to enforce the recyclability of automotive materials within the coming decade, in the following areas: where 1 = extremely probable and 5 = not at all probable.

Regulatory Issues	Mean Rating
Specific regulation for the following:	
Disposal of automotive fluids	1.9
Disposal of used tires	2.0
Recyclability of plastics/polymers	2.3
Establishment of uniform identification/coding standards for materials to facilitate separation	1.9
Ban on some current automotive materials	2.4
Required minimum recycled content	2.9
Financial penalties/incentives based on recycled content	3.0
'Take back' regulations making manufacturers responsible for final product disposition	3.2

Discussion

Panelists forecast that each of the specified issues is at least somewhat probable of regulatory activity. They consider regulations as highly probable concerning the disposal of automotive fluids and tires, and the establishment of uniform identification/coding standards.

Manufacturer/supplier comparison

Results for manufacturers and suppliers are in close agreement.

Comparison of forecast: MAT-6

Technology and materials panelists are in general agreement on this question.

Trend from previous Delphi surveys

This question was asked for the first time in the 1992 Delphi VI survey. Some new issues were added and others were deleted in the present survey. The table below shows a comparison of responses for the issues that were common to the two surveys.

Regulatory Issues	Mean Forecast 1-5*	
	1992 Delphi VI	1994 Delphi VII
Establishment of uniform identification/coding standards for materials to facilitate separation	2.3	1.9
Financial penalties/incentives based on recycled content	3.4	3.0
Disposal of automotive fluids	1.7	1.9
Disposal of used tires	2.2	2.0
Recyclability of plastics/polymers	2.5	2.3
'Take back' regulations making manufacturers responsible for final production disposition	3.5	3.2

* **Scale:** 1= Extremely probable, 5= Not at all probable

Responses between the two surveys are generally in close agreement, but the general trend for the current Delphi is towards higher probability of regulation.

Strategic considerations

Each category could have a significant influence on the design of most automotive components, and likely add to the life cycle cost of the vehicle. This, of course, would influence the affordability/value issue that is so important to customers.

An opportunity exists today for the automotive industry to take a pro-active position with regard to recyclability in order to assure that any future legislation is in the best interest of all concerned and reflects an optimum solution to a given issue. The best solution to a national or international problem will always be found when industry and government work cooperatively. It would appear that technology will have a profound impact on the recycling future. Our opinions are offered on the basis of our present knowledge of technology. All material suppliers and users are engaged in developing new technology that could significantly alter our views on recycling and life cycle management in just the next few years.

TECH-52 What modifications to used vehicles will be required in the next decade to accommodate non-CFC refrigerants?

Responses	Percent of Responses
Minor modifications required	**15%**
Hoses and seals	5%
Lubricant for compressor—new	3
None—performance reduced	3
Air intake—larger; Modest overhaul with some performance loss; Repair leaks	1% each
Minimum modifications: vacuum evacuate to remove residual R-12 and mineral oil lubricants; systems fittings changed to HFC-134A standards, and the accumulator/desiccant changed; system serviced with HFC-134A refrigerant; new lubricant added; new labels affixed to identify conversion to HFC-134A.	
Medium level of modification required	**15%**
Compressor—new	4%
Bigger/added cooling fans and shrouds	3
Cooling system and condenser upgrade	3
Condensers and/or evaporators—larger; run higher pressures; Evaporators—larger; Hoses, condensors and/or evaporators	1% each
Medium level of modifications: Above items plus; hoses; high pressure cut-off switch and associated wiring	
High level of modification required	**11%**
All new components—hoses; compressors; condensers, evaporators	5%
Larger compressor; refrigerant lines—major changes	3
All new, or reduced performance; Fill valves, some hoses and control system calibrations/sensors, fans, compressors, and condensors	1% each
High level of modifications: Above items plus; compressor seals or new compressor, condensers; evaporators; engine cooling system enhancements	
Other	**9%**
Kit—aftermarket	8%
Unlikely due to complex validation issues/multiple different modifications required for compatibility	1

Discussion

Panelists' responses regarding modifications of used vehicles to accommodate non-CFC refrigerants vary widely from minor modifications required, to major modifications required, to not possible. This may result from different strategies or knowledge bases between organizations, as well as uncertainty.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi survey

This question was not asked in any previous Delphi survey.

Strategic considerations

With the total elimination of CFC refrigerants in the next few years, the issue of service of older vehicles built with CFC refrigerants poses an urgent challenge. There are many programs within the industry to address this issue, but as the responses to this question reflect, there is a wide range of opinion as to what the ultimate solution will be.

Moreover, the same solution may not apply to all manufacturers because of the materials and design variations that exist in the current fleet. Since it is likely that this service will in many cases be performed outside of a manufacturers' dealer network, it is highly desirable that the same procedure be applicable throughout the industry in order that all vehicles are properly serviced. The resolution is a prime candidate for a cooperative effort within the industry and service network.

Depending on the ultimate solution found for this service requirement, there could be a significant impact on the new and used car markets. The cost of this service may ultimately influence the useful life of the vehicle. The total cost to society for this change may be great. We believe this will surface as a major public policy issue with significant political overtones. The financial impact of this change is many billions of dollars that ultimately have to come from customers. There is the potential for a very large number of "unhappy campers" as all the ramifications of this change become known.

TECH-53 What new materials or advances in current materials will be available by the year 2003 that will have a significant impact on vehicle interior components? Consider all aspects including cost, durability, appearance, design flexibility, etc.

Material and its impact:

- Certain composite materials that are manufacturer-friendly will emerge.
- Elastomeric filament/fiber materials for seats will find application.
- Electronics will include fiber optic cable for lower weight, better speeds and multiplexing.
- Energy absorbing honeycomb/cell materials for side impact, head impact, etc., will be introduced.
- I foresee airbag covers integral with the I/P crash pad and composites in a modular unibody construction offering the possibility of "stressed" interior components supporting vehicle structure.
- Light-sensitive polymers with low power, high luminance will offer function and design flexibility. Smart materials will begin to find applications in interiors.
- Magnesium components for weight savings will increase.
- PVC-free materials will be introduced, but at possibly higher cost.
- Recycled "fluff/foam" materials for acoustic damping will be used.
- Super elastic material will find seat applications.
- There will be better solar control glass with less fade/degradation and reduced heat.
- There will be improved material compatibility selections for increased recyclability.

Discussion

Many new materials or advances in current materials are suggested in the comments. Opportunities exist in the manufacture and utilization of these advances and may lead to better cost, improved function, improved durability, design flexibility, lighter weight, recyclability, manufacturability and environmental improvement.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi survey

This question was not asked in any previous Delphi survey.

Strategic consideration

The manufacturer or supplier that best utilizes advances in materials will have a financial, design flexibility, manufacturing, mass reduction or customer satisfaction advantage in the marketplace. It is critical, therefore, to monitor new developments or advances continually.

Body and Chassis
Product Trends

TECH-54 What percentage of North American-produced passenger cars will use an integral frame or other designs in MYs 1998 and 2003?

Design	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Integral body/frame or unibody	92%	92%	92%	91/94%	88.9/95%
Separate body/frame	5	4	3	3/5	2/5
Space frame	3	3	5	3/5	3/9
Total	100%	100%	100%	100%	100%

***Source:** *Ward's Automotive Reports*, January, 1993.

Selected edited comments

- Body/frame provides superior ride isolation.
- Low emissions and higher CAFE will drive manufacturers toward space frame/plastic panel design.
- Separate body frame will fade from the scene due to mass inefficiency. Space frame will see increased use in the out-years.

Discussion

Integral body/frame design is forecast to dominate body structure for the next decade, but with continued modest application of separate body/frame and space frame designs.

Manufacturer/supplier comparison

Results for manufactures and suppliers are in close agreement.

Comparison of Forecast: MAT-29

The technology and materials panelists are in general agreement.

Trend from previous Delphi surveys

In the 1987 Delphi IV survey it was forecast that 7 percent of North American-produced passenger vehicles would be space frame by 1995. The 1992 Delphi VI survey forecast only 2 percent space frames in 1995 and 4 percent penetrations of both space frame and separate body/frame by 2000, which is in line with the current survey forecast for 1998 and 2003.

Strategic considerations

Integral body/frame design is forecast to dominate body structure for the next decade. Design improvements continue to be made with body/frame technology, and this should continue. Some recent designs are very stiff, leading to exceptional quietness, ride and handling. Body changes, however, are very expensive because the basic structure is affected when body panels are changed. Fuel economy requirements will continue to support consideration of space frame designs for weight savings and ability to make lower cost changes in body panels, although these advantages appear to be mixed. Some manufacturers have considerable experience with this technology, and may capitalize on this experience if there are cost reduction breakthroughs in plastic/composite materials and construction technologies. The Saturn experience with the space frame is particularly noteworthy. The separate body/frame system, which is almost standard for trucks, continues to be used in several large passenger cars, but there is little enthusiasm to broaden the application level. For all construction technologies, material and process developments could have a profound effect on their future use.

TECH-55 What trend do you expect in vehicle structural stiffness relative to current models, where 1 = significant decrease, 3 = unchanged, and 5 = significant increase?

Vehicle Structural Stiffness Trend	
Year	Mean Rating
1998	3.7
2003	3.9

Selected edited comments

Increasing stiffness (7 responses)

- Better use of materials and computer design will increase stiffness.
- Current vehicles with high stiffness will see little increase, while those with low stiffness will see large increase.
- New noise and handling requirements will drive stiffness increases. Better modeling techniques, plus new composite materials will facilitate this.
- Safety, ride and competitive pressures will drive improved structural characteristics in most market segments by 1998.
- Side impact integrity is required by 1998. This will result in a significant increase in structural stiffness.
- Stiff but very light (loss mass) structures are a must for the future.
- Stiffness is required for NVH, but the effect on crash results must be considered.
- Weight savings and non-traditional materials will result in an increase in stiffness.

Decreasing stiffness (1 response)

- In the years beyond 2000 there may be a decrease in stiffness because of the extensive use of aluminum.

Same stiffness (4 responses)

- A decrease in stiffness will compromise handling.
- An increase in stiffness will compromise crashworthiness.
- Required for NVH, but crash must be considered.
- Structural improvements will level off as CAFE pressures work against diminishing returns for further structural enhancements. This will happen around 1998.

Discussion

Some increase in vehicle stiffness is forecast over the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement on this issue.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Strategic considerations

Vehicles have generally increased in stiffness in the recent past to improve handling and noise. A modest continuation of this trend is forecast, but there are some trade-offs as indicated in the comments. Improved modeling techniques, production processes, and materials may allow increased stiffness without increased weight. Still, the pressure to decrease weight for improved fuel economy may negate some of the potential for increased stiffness. Crashworthiness must be balanced against stiffness. In some cases stiffness means greater safety, whereas in others such as crush energy management, it may be a problem.

In some new vehicles, structural stiffness has been highlighted, which in turn could lead to increased customer sensitivity. Clearly this matter will continue to be a critical design consideration in future vehicles.

TECH-56 What percentage of North American-produced passenger cars will incorporate the following suspension features in MYs 1998 and 2003?

Suspension Features	Median Response		Interquartile Range	
	1998	2003	1998	2003
Front Suspension Configurations				
MacPherson struts	70%	65%	60/80%	50/80%
Twin A-arm	25	30	20/30	20/47
Total	95%	95%		
Rear Suspension Configuration				
Independent	60%	70%	30/75%	40/90%
Non-independent	40	25	25/70	10/55
Total	100%	95%		
Springs				
Air	4%	5%	1/5%	3/10%
Oil/fluid	1	4	0/3	2/5
Composites	5	5	2/6	3/10
Steel	91	85	85/95	70/90
Total	100%	100%		

Other responses include:

Active hydraulics: 1998 - 0 percent; 2003 - 60 percent.

Front Suspension—Active: 2003 - 1 percent.

Rear Suspension—Active: 2003 - 1 percent.

Selected edited comments

- Composites are lighter. The industry is "setting in" on short-long arm front and independent rear.
- Steel springs could go lower, based on weight savings. Air springs will benefit: less weight, height control and improved ride.
- Twin A-arm will see growth. Independent rear suspension configurations will go up, while non-independent configurations will go down. Space, packaging, mass and cost factors will cause non-independent rear suspensions to retrain some market.

Discussion

The trend in suspension systems for the next decade is forecast as follows:

Front Suspensions: MacPherson struts remain the predominant configuration, but with some increasing penetration of twin A-arms.

Rear Suspensions: Independent suspensions will gain in popularity over non-independent systems.

Springs: Steel springs will remain heavily dominant over other alternatives, but lose some ground as oil/fluid springs begin to increase in use.

Large interquartile ranges for both front and rear suspensions indicate uncertainty or differences in opinion throughout the industry with regard to direction.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement regarding springs and front suspensions. There is considerable difference between manufacturers and suppliers on rear suspension configurations, however. The results are summarized below.

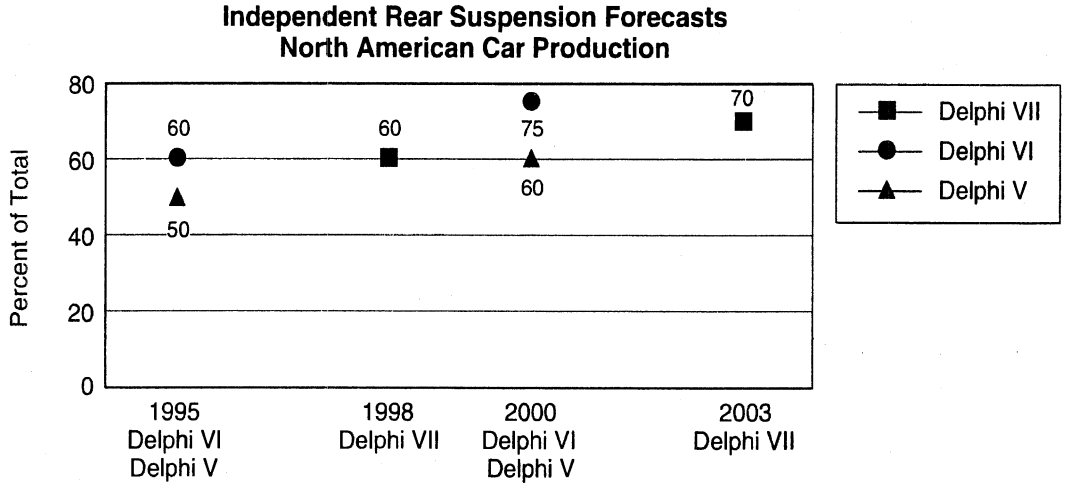
Suspension Features	1998		2003	
	Manufacturers	Suppliers	Manufacturers	Suppliers
Rear suspension configuration				
Independent	65%	35%	75%	50%
Non-independent	35	60	25	50

Trend from previous Delphi surveys

Comparisons of the current survey to past surveys are shown in the following table and graph.

Front Suspension Percent Twin A-arm	1995 MY	1998 MY	2000 MY	2003 MY
1994 Delphi VII	—	25%	—	30%
1992 Delphi VI	20	—	20	—
1989 Delphi V	20	—	25	—

The current survey forecasts a greater use of the twin A-arm design than did the 1992 Delphi VI study, and consequently a lesser use of the MacPherson strut. The current survey is similar to the 1989 Delphi V survey.



The current survey forecasts independent rear suspension usage to be in line with the previous two surveys. However, there is substantial spread between the forecasts, and a wide interquartile range in this forecast, indicating uncertainty and/or differences of opinion between manufacturers regarding this system. The forecast for springs is similar between this and the previous two Delphi surveys.

Strategic considerations

Because of the many economic, technical and customer satisfaction issues related to suspension designs, trends bear careful watching, particularly in light of value and affordability concerns. It would not surprise us to see long-term use of the lowest cost technologies, particularly since lower cost systems have been refined to the point where they are highly functional and appear to provide value and satisfy a large fraction of consumers. We believe we will see the emergence of two basic chassis designs: up-tech, up-scale (pricey and profitable); and a plain-tech, down-scale version. The customer will define the mix between the two. As in most cases, technological developments should be followed closely by all suspension component suppliers.

TECH-57 What percentage of North American-produced passenger cars will have the following chassis/suspension features in 1998 and 2003?

Chassis/Suspension Features	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Active four-wheel steering	0%	0%	1%	0/1%	0/5%
Steering					
Power					
Electrical/electronic	0	1%	5%	0/2%	2/10%
Hydraulic with electronic control	0	5	10	2/10	5/25
Traditional hydraulic	96	90	82	86/94	70/88
Non-power	4	3	2	2/4	0/4
Total	100%	100%	100%		
Ride/Handling					
Passive control (present system)	n/a	90%	80%	85/95%	70/91%
Passive-driver selected	n/a	2.9	5	1/6	1/10
Semi-active (damping controls)	n/a	3	8	2/10	5/15
Active (springs & damping control)	n/a	1	3	0/2	1/6
Total		100%	100%		

Selected edited comments

- Active suspension parasitics will restrict market penetration.
- Electric drive will facilitate electrical power steering.
- Height control (load leveling) will grow.
- Limited perceived value will slow movement toward smart ride/handling controls.
- Semi-active will grow. It gives close to the same benefits as active at a fraction of the cost.
- Variable suspensions will remain a sport/luxury item.

Discussion

Traditional hydraulic power steering and passive suspension control (present system) are expected to remain dominant in the next decade according to panelists. However, other concepts such as hydraulic power steering with electronic control and semi-active suspensions are expected to see limited application.

Manufacturer/supplier comparison

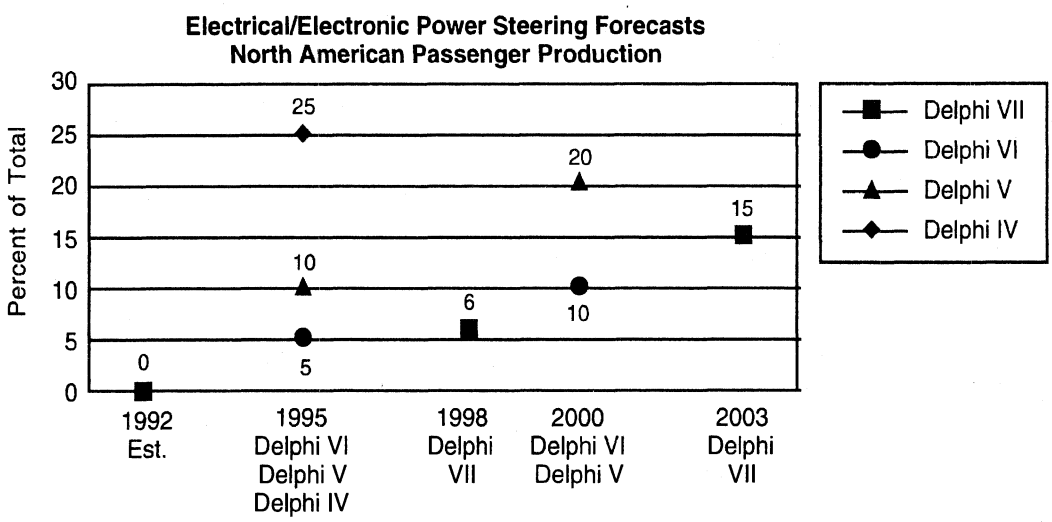
Agreement between manufacturers and suppliers is generally good, with the exception of the forecast for active four-wheel steering in 2003. Manufacturers and suppliers forecasts were 0.5 percent and 5 percent respectively.

Comparison of Forecast: MKT-40

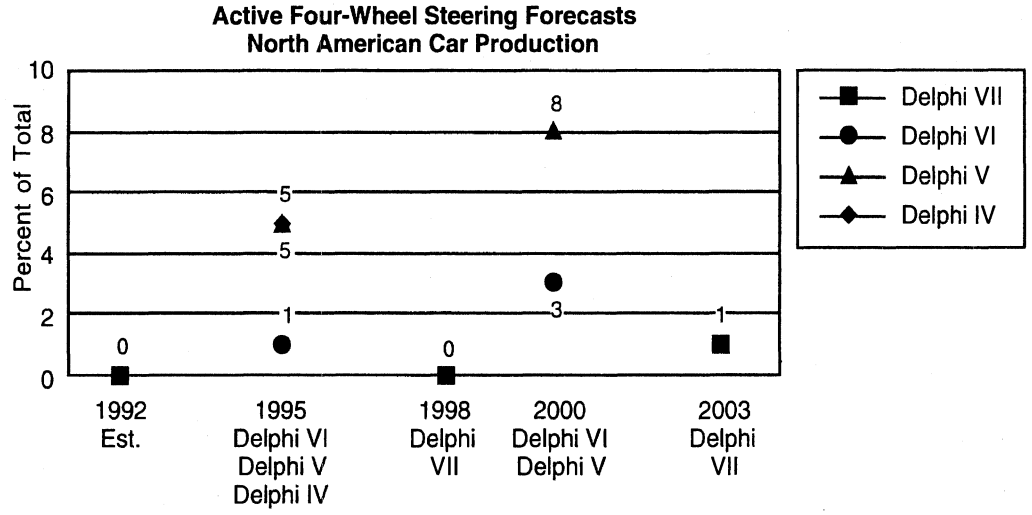
Active suspensions are also addressed in the Marketing survey. The two surveys are in essential agreement for 1998 and 2003.

Trend from previous Delphi surveys

Electrical/electronic power steering was surveyed in 1989 and 1992, but covered all electrical applications to power steering, including hydraulic with electronic control. To compare results, electrical/electronic and hydraulic with electronic control are added together in the graph below.



Results for the 1992 and 1994 surveys are similar. Both project lower application rates than the 1989 Delphi V and 1987 Delphi IV studies.



The forecast for the application of four-wheel steering is negligible, and decreases with each forecast.

1992 Delphi VI Forecast
Percent Penetration of Ride/Handling Systems

	1995 MY	2000 MY
Passive control	88%	78%
Passive-driver selected	5	10
Semi-active (damping control)	5	8
Active (springs & damping)	2	4

Projected application of all ride/handling systems except passive control (present system) are generally the same between the 1992 Delphi VI and 1994 Delphi VII surveys.

Strategic considerations

No large-scale application of sophisticated steering or ride and handling systems is expected in the next decade, according to current panelists, though these features will probably remain of interest in high-priced niche market cars. Major breakthroughs in the cost of these systems could change their outlook, but our panelists do not expect this breakthrough. A key consideration for any of these systems is power consumption and therefore impact on fuel economy. Energy consumption will probably be an important characteristic of any future system.

A point of interest particularly with regard to active four-wheel steering (which took the industry by storm several years ago) is that the sizzle is often better than the steak. The customer voted it down, and it languishes with other interesting but expensive ideas waiting for a new generation of affluent customers.

Again we see the importance of balance between affordability and function. Most sophisticated, robust and elegant designs are generally simple and inexpensive. As in most areas of the vehicle there is considerable opportunity for creative and innovative thinking.

TECH-58 What percentage of these North American-produced vehicles will use rear disc brakes in 1998 and 2003?

Rear Disc Brakes	Est. 1991*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Passenger cars	21%	25%	35%	25/30%	30/50%
Pickups	0.1%	1	5	1/5	2/15
Vans	0%	2	5	1/5	5/20

***Source:** *Automotive News 1992 Market Data Book.*

Selected edited comments

- While most vehicles do not need them, rear disc brakes will become lighter and cheaper than drums.

Discussion

Rear disc brake use is expected to increase modestly in passenger cars but have limited application to pickups and vans in the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are in close agreement.

Comparison of forecast: MKT-41

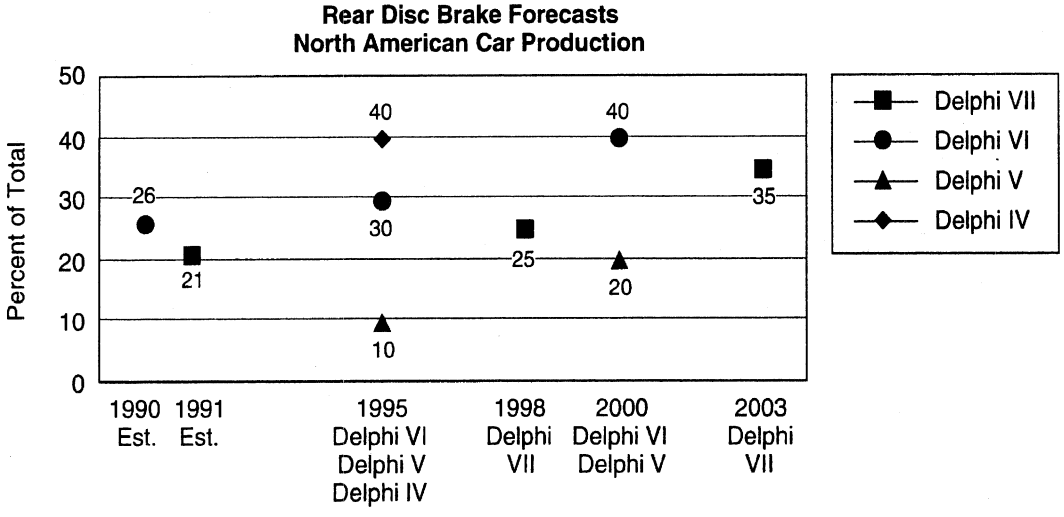
The technology and marketing surveys are in agreement for pickups and vans. Results for passenger cars are summarized below. The projected gain over a 10-year period is the same between technology and marketing surveys.

Passenger Cars With Rear Disc Brakes	1998		2003	
	TECH	MKT	TECH	MKT
	25%	20%	35%	30%

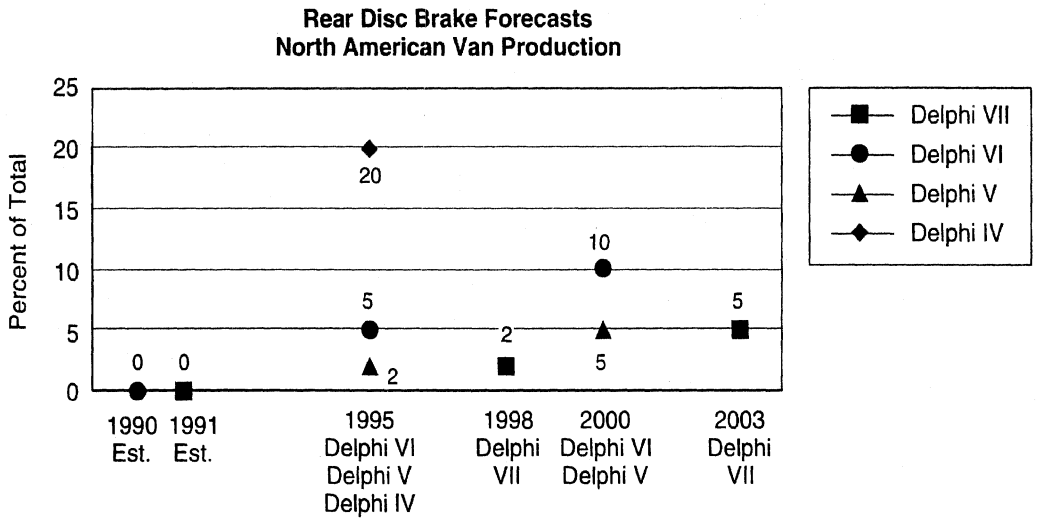
Trend from previous Delphi surveys

The application rate of rear disc brakes in pickup trucks in the current survey is similar to that of the past two surveys. However, this rate was projected to be as high as 15 percent by model year 1995 in the 1987 Delphi IV survey.

Application rates in passenger cars and vans are summarized below.



The forecast for the application rate of rear disc brakes in passenger cars has changed markedly over the past four Delphi surveys. The results of this survey fall between those of the 1989 Delphi V and 1992 Delphi VI surveys.



Results of this survey are in line with the 1989 and 1992 surveys, but are considerably below the forecast from the 1987 Delphi IV survey.

Strategic considerations

The primary application of rear disc brakes is in passenger cars, and is projected to remain that way for the foreseeable future. The projected usage in passenger cars varies widely across Delphi surveys. This high degree of variability may be due to uncertainty regarding the functionality and cost of disc brakes versus drum brakes in the future. Another factor may be the changing perceived value to the customer for disc brakes at a premium price. In some cases rear disc brakes may have been installed in vehicles because of the known engineering attributes, but these attributes may not be known, or of any concern, to the customer. In front wheel drive vehicles, the rear brakes contribute a relatively small fraction of the total braking effort, and may not justify a premium cost brake system. With today's increasingly cost conscious, value-focused customer, manufacturers must deliver performance, but at the lowest cost. In this context, the variability of these forecasts over the years is understandable.

The design challenge of getting an effective parking brake with rear disc brakes may be another factor in the indecision over the application of rear disc brakes.

TECH-59 What percentage of North American-produced passenger cars will be equipped with antilock brakes and traction control in 1998 and 2003?

Brake and Traction Control Features	Est. 1991*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Antilock brakes	19.0%	60%	90%	60/70%	85/100%
Traction control (anti-spin)	0.2%	5	20	2/10	8/40
Powertrain and brakes		5	15	2/10	8/30
Powertrain only		5	20	2/10	10/25

***Source:** *Automotive News 1992 Market Data Book.*

Selected edited comments

- It will be 100 percent based upon assumption of NHTSA requirement.
- If costs continue to come down, penetration could be quite high.
- Partial-function traction control (via powertrain controls) could approach 100 percent.
- Potential to become litigation target exists for those few applications where ABS is not standard by 2003.
- Safety and insurance rates will drive adoption.

Discussion

Antilock penetration is forecast to approach 100 percent during the next decade. Traction control is expected to see an application rate of 20 percent in the same time frame.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

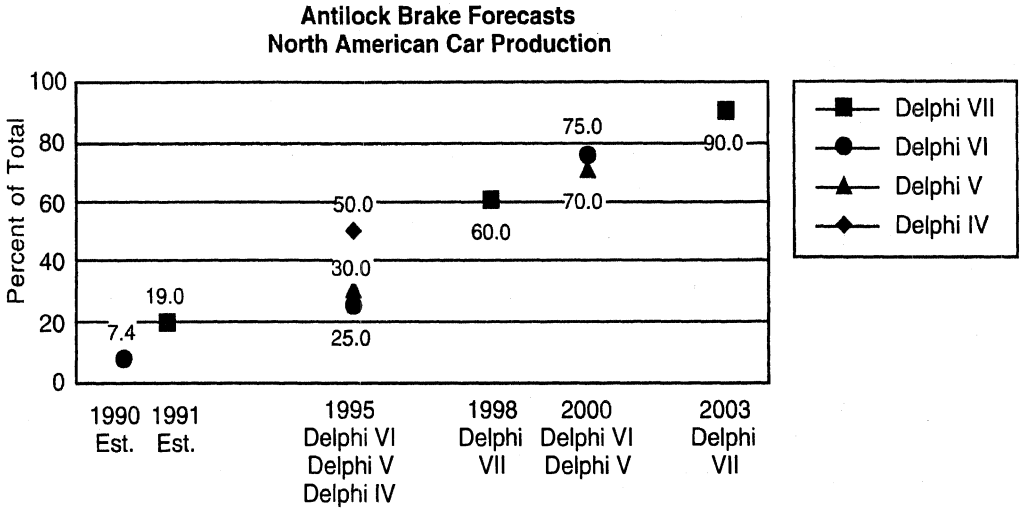
Comparison of forecast: MKT-36

Technology and marketing panels are in agreement with regard to traction control. The results for anti-lock brakes are summarized below.

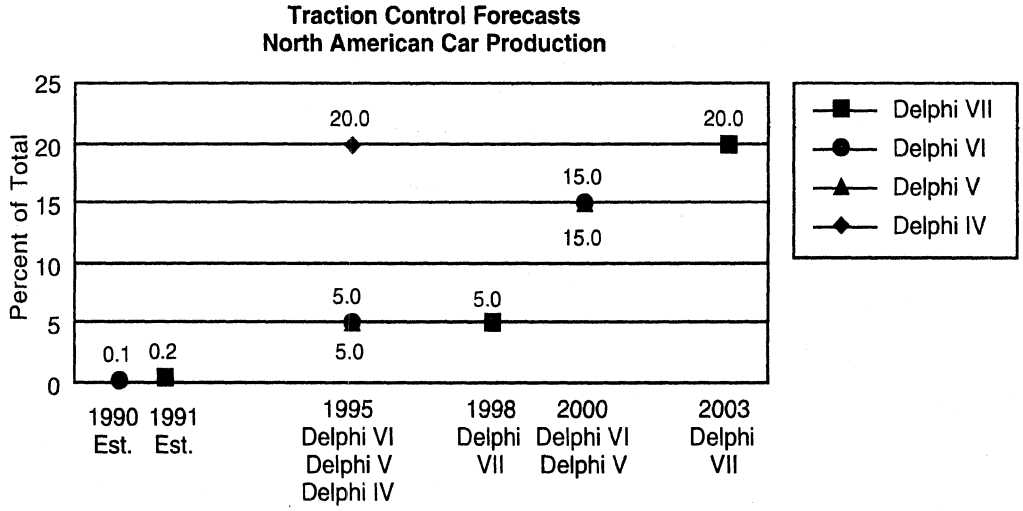
Anti-lock brakes	1998		2003	
	TECH	MKT	TECH	MKT
	60%	40%	90%	75%

Technology panelists forecast higher penetration of anti-lock brakes for 1998 and 2003. Marketing panelists may be more influenced by the cost of this feature.

Trend from previous Delphi surveys



Results of the current survey are in line with previous forecasts.



The current survey is in agreement with the last two surveys. The 1987 Delphi IV forecast is extremely high in its projection for 1995.

Strategic considerations

Delphi forecasts indicate that the application of ABS brakes will approach 100 percent in the next 10-15 years. This is a market-driven move as customers realize the safety benefit of this feature. It is unlikely that legislation will be required to achieve 100 percent application of this system, and legislation, if it comes, may be superfluous. System costs have dropped dramatically in the past few years to further accelerate the application of ABS.

Projected application of traction control lags that of ABS. This system is more a customer convenience than a safety feature, and is probably recognized as such by the customer. Powertrain only control of wheel slip can be achieved at a very low cost, but is also of modest value. This system may see widespread application because of the low cost, however.

Full engine and brake traction control is facilitated with the accelerating application of ABS brakes. It should be noted that some of the key traction control hardware is included with ABS systems and the incremental requirements beyond ABS are modest but still reasonably costly. The value to the customer is greatest in rear drive vehicles, but rear drive vehicles only represent about 13 percent of the passenger car market today, and the penetration is projected to decline. Full engine and brake traction control will probably remain an upscale feature purchased by

TECH-60 What percentage of North American-produced passenger cars will have standard spares, minispares, airless spares, or no spares in the 1998 and 2003 model years?

Types of Spare Tires	Est. 1991*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Standard spare	7%	5%	3%	5/5%	1/5%
Minispare	93	93	90	90/95	82/94
No spare	0	0	2	0/2	0/10
Airless spare		0	1	0/1	0/5
Total	100%	100%	100%	100%	100%

***Source:** *Automotive News 1992 Market Data Book.*

Selected edited comments

- Desire to optimize luggage compartment volume/useability will reduce full size space applications.
- Need for reduced weight and more space will drive "run-flat" tire use.
- The no-spare option depends on the success of "run-flat" tires recently introduced to OEMs.

Discussion

Panelists forecast that the minispare will continue to be dominant in the next decade, with very limited application of the currently identified alternatives.

Manufacturer/supplier comparison

Manufacturers and suppliers are in close agreement.

Trend from previous Delphi surveys

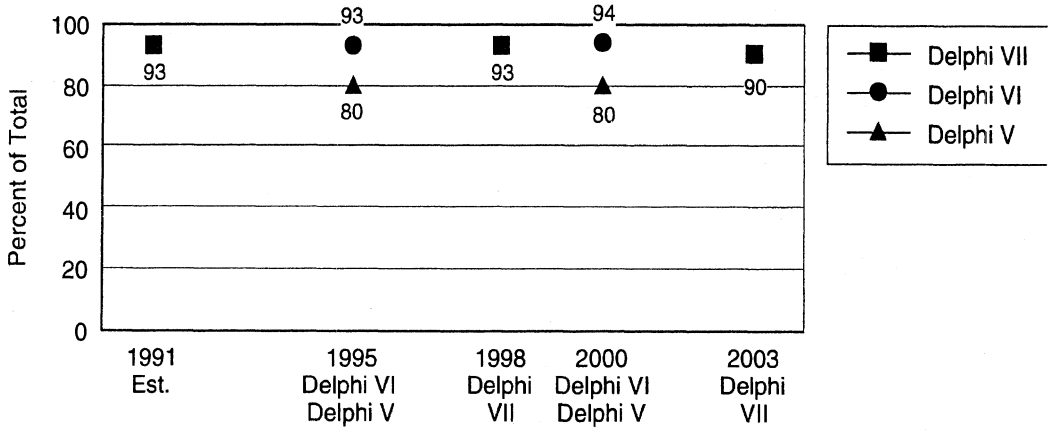
The category of airless spare was added in this survey.

No Spare: Results between the 1994 Delphi VII and 1992 Delphi VI surveys are in agreement. In the 1989 survey, no spare was predicted to be represented in 5 percent of passenger cars in 1995 and 10 percent in 2000.

Standard Spare: Results between the 1994 Delphi VII and 1992 Delphi VI surveys are in agreement. In the 1989 Delphi V study, a standard spare was predicted to represent 15 percent of passenger cars in 1995 and 10 percent in 2000.

Minispare: The comparison to past surveys is shown in the following graph.

Mini-Spare Usage Forecasts
North American Car Production



Results are similar between the 1992 and 1994 surveys. Lower application rates were forecast in the 1989 Delphi V survey.

Strategic considerations

It is probably time to change the name of "standard" spare to full-sized spare, as the minispare is forecast to be used in the vast majority of vehicles in the next decade. Very limited use of airless spares is projected as is elimination of spares. The advent of a low cost reliable run-flat tire could change this trend, but that is not predicted, as seen in the next question.

Elimination of the spare tire would be very advantageous from a weight- and space-saving standpoint, but our panel indicates that the time for this change is not near. In some of our early Delphi forecasts there was far greater optimism for run-flat tires and spare tire elimination. Technology has just not lived up to those expectations.

TECH-61 What percentage of North American-produced passenger cars will incorporate the following tire features?

Tire Features	Median Response		Interquartile Range	
	1998	2003	1998	2003
Failure sensing devices	2%	10%	1/3%	5/10%
Puncture resistant/self sealing	5	15	5/5	10/20
Run-flat	2	10	2/5	5/20

Selected edited comments

- Failure and loss of pressure (say 30 percent or more) can be detected by the software in ABS, hence sensing devices will not be needed.
- Failure sensing devices do not include tire pressure estimation via software techniques.
- Failure sensing will be used in conjunction with run-flat and self-sealing tires.
- Pressure maintenance and self-filling systems would help actual fuel economy.
- Puncture resistant/self sealing features will increase. Ride/cost/mass trade-offs must be resolved.
- The key issue will be getting a system good enough to eliminate the need for a spare and jack.
- These product features will sell on safety. The less safe our cities and streets become, the better these will sell as our median age moves up.
- Tires are becoming so reliable that the push for puncture resistance or run-flat capability is diminishing.

Discussion

A small but growing application of tire failure sensing devices, puncture resistant and run-flat tires is forecast.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Results of the previous two forecasts are compared to the current survey in the table below. The categories of puncture resistant and self-sealing have been combined in the current survey.

Tire Features	1995		1998	2000		2003
	Delphi V	Delphi VI	Delphi VII	Delphi V	Delphi VI	Delphi VII
	1989	1992	1994	1989	1992	1994
Failure sensing	2%	1%	2%	8%	5%	10%
Puncture resistant	20	5	—	30	10	—
Self-sealing	10	5	—	12	10	—
Run-flat	5	1	2	10	5	10

The current survey results for puncture resistant/selfsealing are essentially the same as those for each of the categories (puncture resistant and self sealing) of the previous 1992 Delphi VI survey. Projections are considerably less, however, than forecast in the 1989 Delphi V survey, particularly with regard to puncture resistant tires.

The trend for failure sensing is similar for the past three surveys.

The past two surveys are in close agreement with regard to run-flat, but projections are well below those of the 1989 Delphi survey.

As with many new technologies or features, the application rate of these tire features is delayed as the forecast date of application approaches.

Strategic considerations

Panelists project a presence in the marketplace in the next decade for each of the features under consideration. The application rate is substantially less than that forecast in the 1989 Delphi V survey, however. Cost is likely to be the limiting factor to widespread use of each of these technologies. Initial applications will certainly be in luxury or niche markets.

The widespread use of run-flat tires may come about if the fuel economy standards are more restrictive than forecast in this survey. The value of the projected weight savings can be predicted by reference to TECH-49 for any given size/weight tire eliminated. This assumes, however, that the rolling resistance will not increase with run-flat tires, as any increase would offset weight saved from a fuel economy standpoint.

TECH-62 What percentage of North American-produced passenger cars and light trucks will incorporate driver, front passenger, and rear seat airbags in 1998 and 2003?

Airbag Applications	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Passenger Cars					
Driver side	51%	90%	100%	70/100%	95/100%
Passenger side	4	50	90	25/75	50/100
Rear seat occupants	0	2	10	0/5	3/25
Side airbags	0	1	5	0/5	1/10
Light trucks					
Driver side	10%	50%	95%	30/80%	75/100%
Passenger side	0	20	50	5/40	20/100
Rear seat occupants	0	0	0	0/0	0/5
Side airbags	0	0	0	0/2	0/6

* **Source:** *Ward's Automotive Reports,* December, 1993 and various OSAT estimates.

No comments

Discussion

Airbag application rates for the driver side in passenger cars and trucks is expected to be at or near 100 percent by 2003. Passenger side airbags are expected to approach 100 percent in passenger cars and 50 percent in trucks in the same time frame. Rear seat occupant and side airbags are expected to see limited or no application in passenger cars and trucks during this period.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Light trucks were not addressed in previous surveys. The forecast for passenger cars is in general agreement with past surveys, with the exception of lower projections for side airbags in the current survey. The 1992 Delphi VI survey forecast 10 percent side airbags on the drivers side and 5 percent on the passenger side by 2000.

Strategic considerations

The interquartile range for passenger cars is quite high for passenger side, rear seat occupant, and side airbags, reflecting uncertainty or divergence of opinion within the industry. The significant cost to apply these devices raises questions as to the customers' acceptance of this added cost. It is likely that the customer will accept the cost of passenger side airbags, but less likely side and rear airbags. If legislation forces these devices into the marketplace, the added cost could have a negative impact on total vehicle sales and/or shift the market down-scale. Of course, new low-cost technological developments or other incentives such as insurance premium reduction could alter this concern rather significantly.

There is very good agreement that driver side airbags in passenger cars will be at, or approach, 100 percent by 2000. This is clearly a market-driven trend, even though legislation is in place to require passive restraints. Light truck driver side airbags are also projected to approach 100 percent by 2000.

TECH-63 What percentage of airbag sensors in North American-produced passenger cars will be either mechanical or electronic by the following years?

Airbag Sensors	Median Response		Interquartile Range	
	1998	2003	1998	2003
Mechanical airbag sensors	50%	10%	20/60%	5/30%
Electronic airbag sensors	50	90	40/80	70/95

Selected edited comment

- I am aware of new and promising mechanical sensor technology.

Discussion

Based on currently known and expected future technology, panelists forecast a shift from mechanical to electronic airbag sensors. Obviously a breakthrough in either technology could alter or accelerate this trend. The single edited comment suggests the potential of such a breakthrough.

Manufacturer/supplier comparison

Manufacturers and suppliers are in close agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey. The results of the two surveys are in close agreement.

Strategic considerations

The industry has gained considerable experience with airbag systems. Any significant change to these systems will come only after extensive testing for reliability. Panelists currently believe that this testing will prove the reliability and cost effectiveness of electronic sensors.

TECH-64 What percentage of vehicles produced in North America will have the following IVHS systems by 2003?

IVHS Technologies	Median Response	Interquartile Range
Adaptive cruise control	5%	2/10%
Collision warning systems	8	5/10
Automatic toll collection	5	1/15
Navigation	5	2/15
In-vehicle message system	10	5/25

Selected edited comments

- Assume that in-vehicle message systems will include voice mail or cellular phones.
- Cost is the reason these systems will not have a significant impact. With wages nearly static, disposable income will take a hit. Higher taxes will do the rest.
- Independent IVHS features like adaptive/radar cruise and collision warning will slowly spread from top end production initial applications.
- Lack of infrastructure will continue to hold back IVHS.
- The dislocation of jobs will cause consumers to be very price conscious.
- These are nice high tech ideas, but they are too costly now. There is little prospect of getting cost down enough that many consumers will buy them.

Discussion

Limited application of IVHS technologies including in-vehicle message systems, collision warning systems and adaptive cruise control is forecast by 2003.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi survey

This question was first asked in a similar format in the 1992 Delphi VI survey. The categories were different, however, with the exception of collision avoidance. Results are summarized below.

IVHS Category	By 2000 1992 Delphi VI	By 2003 1994 Delphi VII
Collision warning	0%	8%
Motorist service information	40	—
Cooperative route guidance	15	—
Vehicle location and identification	10	—
Autonomous vehicle navigation	10	—
Speed and highway keeping	10	—
Automated highway chauffeuring	2	—

Comparison of forecast: MKT-37

Questions regarding adaptive cruise control and collision warning systems were asked in the Marketing survey. A comparison between the two surveys is shown below.

IVHS Technology	Median Response	
	TECH	MKT
Adaptive cruise control	5%	7%
Collision warning systems	8	5

Strategic considerations

Panelists forecast limited application of IVHS technologies by 2003. Based on the comments, cost is expected to be the limiting factor. These technologies will likely first appear in upscale vehicles where they can be used as a niche discriminator. Even in an upscale vehicle however, the customer may question the added complexity of these systems, as evidenced by the comments. However, we have learned in the last few years that safety is becoming increasingly attractive to customers, and they will make the final decision assuming, of course, it is a cost-effective technology.

TECH-65 What percentage of North American-produced passenger car engines will be equipped with the following number of cylinders in 1998 and 2003?

Passenger Cars Number of Cylinders	Est. 1992*	Median Response 1998	Median Response 2003	Interquartile Range 1998	Interquartile Range 2003
3	1%	1%	2%	1/2%	1/4.5%
4	42	42	44	40/45	40/50
6	41	42	43	40/45	38.6/46
8	15	12	10	6/13	6/14
10/12	<1	1	1	0/1	0/1
Total	100%	98%	100%		
Light Trucks Number of Cylinders	**Est. 1992***	**Median Response 1998**	**Median Response 2003**	**Interquartile Range 1998**	**Interquartile Range 2003**
3	0%	0%	0%	0/0%	0/0%
4	12	13	15	10/15	10/20
6	59	60	60	59/60	56/65
8	29	25	23	25/30	20/28
10/12	0	0	0	0/1	0/1
Total	100%	98%	98%		

***Source:** *Ward's Automotive Reports*, January, 1993.

Selected edited comments

- The engines will move to lower displacement, improved specific output and lower friction.

Discussion

For passenger cars, eight-cylinder engine usage is forecast to decline for the next decade, with both four- and six-cylinder engine penetration increasing slightly. This forecast is in line with the expectations for required increases in fuel economy and the projected overall weight of the vehicle. The magnitude of the anticipated change in number of cylinders would indicate that fuel economy standards are not expected to rise dramatically in the next decade.

Trends are similar for light trucks, but the penetration of eight-cylinder engines is forecast at more than twice that of passenger cars. The eight-cylinder engine is still seen as a requirement for carrying the heavy loads associated with the use of many light trucks. Light trucks are used for trailer hauling by many customers, in addition to the normal cargo hauling capacity of the vehicle itself.

Manufacturer/supplier comparison

Manufacturers and supplier are in agreement.

Trend from previous Delphi surveys

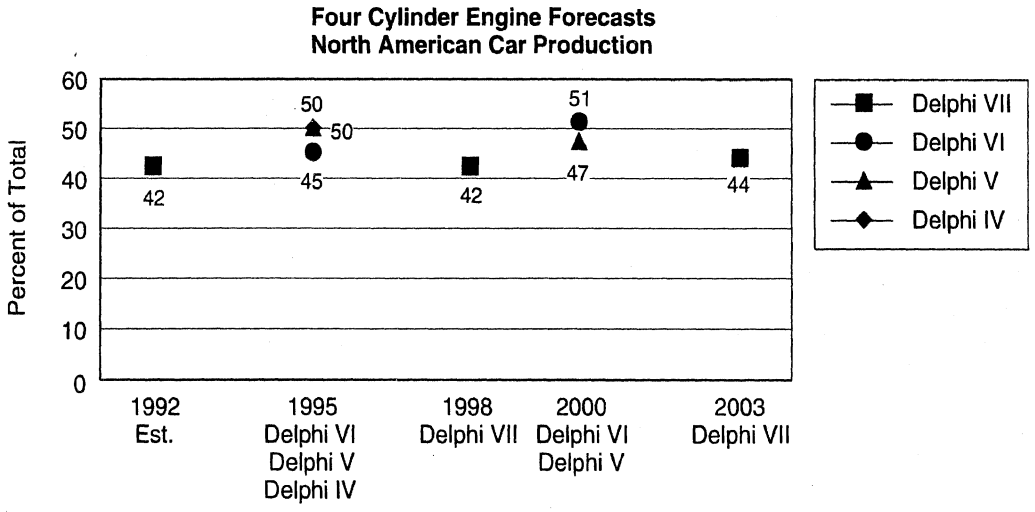
Results from previous surveys are summarized below.

Number of Cylinders	1995			1998	2000		2003
	Delphi IV	Delphi V	Delphi VI	Delphi VII	Delphi V	Delphi VI	Delphi VII
Passenger Cars	1987	1989	1992	1994	1989	1992	1994
3	2%	0%	0%	1%	1%	3%	2%
4	50	50	45	42	57	51	44
6	35	30	40	42	35	35	43
8	13	20	15	12	17	11	10
10	—	0	0	1	0	0	1
Light Trucks							
3	—	—	—	0%	—	—	0%
4	45	14	15	13	15	20	15
6	35	50	50	60	50	50	60
8	20	36	35	25	35	30	23
10/12	—	—	—	0	—	—	0

Passenger cars

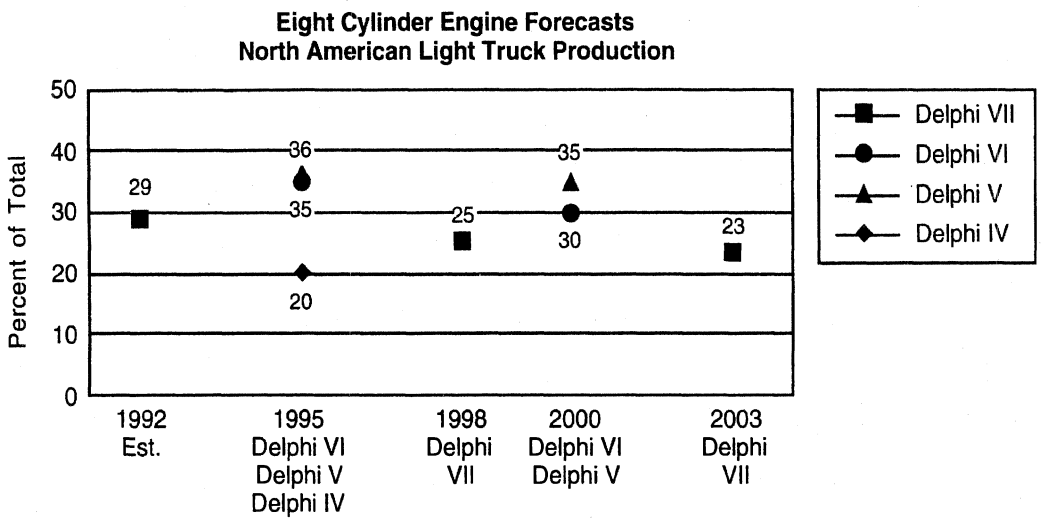
The current panel forecasts a relatively constant penetration of four-cylinder engines in the next decade. The 1992 Delphi VI survey forecast an increase in penetration. The difference in these forecasts translates directly to a trade-off with six-cylinder engines, which remain nearly constant with time in this survey.

Results are similar between Delphi VII and previous surveys with the exception of a shift between four- and six-cylinder volumes. Forecasts for four-cylinder engines are summarized below.



Light Trucks

Compared to the previous two surveys, respondents to the current survey forecast similar four-cylinder, greater six-cylinder, and less eight-cylinder penetration. The past three surveys have forecast the six-cylinder engine to dominate in the 1995-2003 time frame. The 1987 Delphi survey participants forecast significantly more four-cylinder, less six-cylinder, and a similar numbered eight-cylinder engines compared to the current survey.



Strategic considerations

The reduction in the average number of cylinders will mean slightly reduced volume for suppliers of pistons, connecting rods, valves and associated components—assuming constant vehicle sales.

TECH-66 What percentage of six-cylinder engines in North American-produced passenger cars and light trucks will be V-6 and what percentage will be In-line (IL-6)?

6-Cylinder Engines	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Passenger Cars					
V-6	100%	100%	100%	100/100%	100/100%
IL-6	0	0	0	0/0	0/0
Light Trucks					
V-6	82%	85%	90%	85/95%	82/100%
IL-6	18	15	10	10/15	2/18

***Source:** *Ward's Automotive Reports*, December 1992 and January, 1993.

Selected edited comment

- Cars require a move to longitudinal configuration which may only occur in the luxury car segments. This may then carry over to the truck market.

Discussion

The IL-6 engine is not expected to be used in passenger cars, and is forecast to see a declining application rate in light trucks in the next decade.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Passenger cars: The current survey indicates no IL-6 engines will be produced in the next decade. The 1992 Delphi VI survey forecast a 10 percent penetration of IL-6 engines in 1995 and 2000.

IL-6 Engines in Light Trucks	Est. 1992	1995	1998	2000	2003
1994 Delphi VII	18%	—	15%	—	10%
1992 Delphi VI	—	25	—	20	—

***Source:** *Ward's Automotive Reports*, December 1992 and January, 1993.

The trend towards fewer IL-6 engines in light trucks is similar for the last two surveys, but the level is lower for the present survey.

Strategic considerations

The IL-6 engine is not forecast to be used in passenger cars, and may see a decreasing penetration in light trucks, according to our panelists. The inherent advantages of dynamic balance and low cost are offset by compromises in styling and underhood packaging required for this engine with transverse mounting, which is prevalent in passenger cars today. Since many engine designs are used in both passenger cars and trucks, the move to V-6 engines in trucks provides more commonality with passenger cars, thus increasing manufacturing flexibility and reducing the total number of engine types required for a manufacturer. This limits IL-6 usage, however.

There is a possibility if T-drive is used in the future in passenger cars that IL-6 engines would be required. Our panelists do not see this design surfacing in the next decade.

TECH-67 Please indicate the percentage mix of spark-ignited engine displacements you expect in North American-produced passenger cars in MYs 1998 and 2003.

Passenger Cars Displacement in Liters	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
5.1+	2%	2%	1%	1/2%	1/1%
5.0-4.1	13	10	10	10/12	6/10
4.0-3.1	33	31	30	30/35	25/35
3.0-2.1	31	33	34	31/35	30/38
2.0-1.5	20	20	20.8	19/24	20/28
Below 1.5	1	1	1	1/1	0/3
Total	100%	97%	96.8%		

*Source: *Ward's Automotive Reports*, December, 1992.

No comments

Discussion

Modest engine displacement downsizing is expected in the next decade by our panelists.

Manufacturer/supplier comparison

Manufacturers and suppliers are in close agreement.

Trend from previous Delphi surveys

Passenger Cars Displacement in Liters	1995			1998	2000		2003
	Delphi IV 1987	Delphi V 1989	Delphi VI 1992	Delphi VII 1994	Delphi V 1989	Delphi VI 1992	Delphi VII 1994
5.1+	2%	3%	1%	2%	2%	0.5%	1%
5.0-4.1	10	18	11	10	16	8	10
4.0-3.1	26	21	30	31	21	29	30
3.0-2.1	36	50	40	33	51	40	34
2.0-1.5	21	10	18	20	10	20	20.8
Below 1.5	5	0	0.5	1	0	3	1

This survey, and the last, project a reduction in the 5.0-3.1 liter range and an increase in the 3.0-2.1 liter range compared to the 1992 estimate in the next decade. Other engine sizes remain little changed.

Strategic considerations

The current forecast projects modest engine downsizing in the next decade. This downsizing may be possible because of the following factors:

1. Increased specific power for pushrod, overhead cam and multivalve overhead cam engines.
2. Reduced vehicle weight, including lower engine weight with shift to lighter materials and more compact designs.
3. Vehicle downsizing.
4. Transmission design changes, including number of forward gear ratios and electronic integration with the engine.
5. Minor performance/fuel economy trade-offs.

Specific power will increase through an increase in number of valves per cylinder, camshaft material changes in pushrod engines, increased use of port fuel injection, reduced friction, moves from pushrod to overhead cam, optimized spark, fuel control, generally increased precision and other design changes.

The push for increased fuel economy will drive this trend toward lower engine displacement. A conflicting consideration will be the demand for performance in the marketplace driven by low fuel prices. Another conflicting consideration is noise, in that a large engine running slow will produce less noise than a small engine running fast. Of course, even modest CAFE increases could have a profound effect on these forecasts.

TECH-68 Please indicate the percentage mix of spark-ignited engine displacements you expect in North American-produced light trucks in MYs 1998 and 2003.

Light Trucks Displacement in Liters	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
5.1+	21%	20%	17%	18/20%	13/20%
5.0-4.1	29	29	27	27/30	25/30
4.0-3.1	27	28	29	27/30	27/34
3.0-2.1	22	23	25	21/25	20/27
2.0-1.5	1	1	1	0/2	0/3
Below 1.5	0	0	0	0/0	0/0
Total	100%	101%	99%		

***Source:** *Ward's Automotive Reports*, January, 1993.

Selected edited comments

- It will stay about the same. Commercial trucks still require V-8s. The 4.0/3.1 and 3.0/2.1 may move to the lower end of their range.

Discussion

As in passenger cars, light truck engines are expected to experience modest downsizing in the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are in close agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey. The results are shown below.

North American-Produced Light Trucks Displacement in Liters	1995	1998	2000	2003
	Delphi VI 1992	Delphi VII 1994	Delphi VI 1992	Delphi VII 1994
5.1+	25%	20%	20%	17%
5.0-4.1	30	29	29	27
4.0-3.1	20	28	21	29
3.0-2.1	24	23	28	25
2.0-1.5	1	1	2	1
Below 1.5	0	0	0	0

Both the 1992 Delphi VI survey and the current survey forecast a decrease in the 5.1L+ size category and an increase in the 3.0-2.1L category.

Strategic considerations

The factors noted in the displacement trends of passenger car engines (TECH-67) apply here also, but with the added constraints of commercial use, fleet purchase incentives, etc. Increased sales of sport utility vehicles and minivans may also contribute to general downsizing of engines. Increased CAFE requirements will cause a trend toward engine downsizing, as in passenger cars. Generally engines for light trucks and vans do not need to be as up-tech as passenger cars. Consequently, there may not be the pressure to increase specific power. Furthermore, these vehicles are often designed for specific load requirements, which means downsizing is difficult.

TECH-69 What percentage of current North American-produced engines will undergo major redesign (> 30% or more of the investment cost of a new engine) by 1998 and 2003?

North American-Produced Engines	Median Response		Interquartile Range	
	1998	2003	1998	2003
Four-cylinder engine	30%	50%	25/30%	50/70%
V-6 engine	30	60	30/40	50/75
V-8 engine	20	40	20/30	30/70

Selected edited comments

- All cast iron V-6 are being (but have not yet been) replaced.
- Engine technology will change with improved sensors and control strategies, more than by major redesigns.
- GM and Ford have just tooled their new V-8s. There's little change.
- This is very dependent on CAFE, which is very unclear. High capital/long leadtime vs. unclear requirements would imply only a gradual rate of redesign.
- V-8 engines may phase out for passenger cars but is increasing for light duty trucks. Two-stoke engines will become more popular by 2003.
- V-8 engines will phase out.

Discussion

Panelists expect approximately half of all engines will undergo major redesign by 2003, and almost one third by 1998.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Percent of current North American-produced engines undergoing major redesign:

North American-Produced Engines	1998	2000		2003
	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Four-cylinder engine	30%	70%	65%	50%
V-6 engine	30	65	60	60
V-8 engine	20	60	50	40

It is difficult to make direct comparisons in this question, since it is not possible to know how much redesign has already taken place that was forecast in previous surveys. It can be said, however, that panelists expect somewhat less redesign in the next decade than was forecast for the decade following the previous two surveys.

Strategic considerations

Compared to past forecasts, this survey forecasts a decrease in engine redesign. This change in outlook may be due to these factors:

- Increased capital constraints.
- Advances in design by evolution rather than revolution. This may include application of new materials to selected components, new sensors with new applications and increased sophistication in software for engine control. An example of evolution is the use of steel camshafts to allow faster rise time of the valves, thereby increasing power.
- Personnel limitations as a result of downsizing and competition for other programs such as emissions.
- Recent engine redesigns that make future redesigns unnecessary.
- A change in philosophy regarding the need or desirability of multivalve engines.

In spite of the reduction in redesign activity forecast, a significant level is still projected. This redesign effort, coupled with the effort required to meet new emission standards, will provide a major challenge to engine designers in the next decade. Engine redesign requires significant capital at a time when other capital demands of the industry are extraordinary. Top management must deal with tough decisions to balance, for example, expansion in some international market against a new engine at home. We believe the complex challenges of the international business will demand agility and flexibility which could substantially alter the engine redesign forecast.

TECH-70 What percentage of North American-produced passenger cars and light trucks/vans will be equipped with diesel engines in 1998 and 2003?

Diesels	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Passenger cars	0.0%	0%	0%	0/1%	0/4%
Light trucks/vans	3.3	5	7	3/5	3/10

***Source:** *Ward's Automotive Reports*, January, 1993.

Selected edited comments

- Current forecasts show no dramatic increases in U.S. fuel costs are expected indefinitely. Unless there are government incentives, diesel will remain a minor factor in light duty service.
- Politics on emissions restrict us from doing sensible things to save fuel.

Discussion

Panelists expect limited use of diesel engines in light trucks and vans, and no application in passenger cars by 2003.

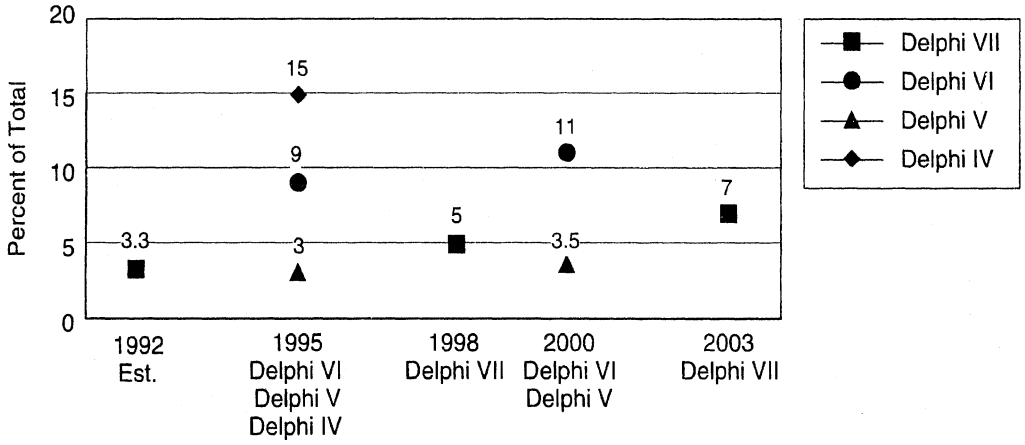
Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Passenger car diesel engine use has been projected to be nearly zero for the past four Delphi surveys, except that the 1992 Delphi VI survey forecast 2 percent application by 2000 and the 1987 Delphi IV survey projected 3 percent application by 1995.

Diesel Engine Forecasts
North American Light Truck Production



Diesel engine use in light trucks and vans for the next decade is projected to be on the low side of previous surveys.

Strategic considerations

With the current outlook for gasoline prices, there is no apparent market for diesel engines in passenger cars, particularly considering past experience and problems of high cost, odor, noise and difficulty in controlling emissions. In light trucks, a small and slowly growing market in the next decade is forecast. Many light trucks are used in conjunction with agriculture and construction applications, where other diesel powered equipment (and consequently fuel) is present, and noise issues are minimal. The total number of miles driven per year by many truck owners may also justify the initial cost of a diesel engine when considering the fuel savings of a diesel.

Emissions standards for diesels have made the future application rate difficult to forecast due to the technology breakthroughs required. The diesel engine has an inherent particulate (soot) and nitrogen oxide emission problem. The diesel future is still somewhat clouded (no pun intended) today.

TECH-71 What percentage of North American-produced passenger cars will use two-stroke gasoline engines in MYs 1998 and 2003?

	Median Response		Interquartile Range	
Two-Stroke Engines	1998	2003	1998	2003
	0%	3%	0/1%	2/5%

Selected edited comments

- It is not a cost-effective way to meet LEV standards for California. Control systems will be too expensive.
- Pending emissions regulations will eliminate two-stroke as a viable passenger car engine.
- This depends on emissions and success of new fueling techniques/durability.
- This niche depends on just how high gasoline prices will rise with taxes.

Discussion

Limited application (3 percent in 2003) of two-stroke gasoline engines is foreseen in the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

	1995			1998	2000		2003
Two-Stroke Engines	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
	3%	0%	0%	0%	2%	5%	3%

The current Delphi forecast for two-stroke engines is on the low side of previous forecasts for the next decade.

Strategic considerations

In spite of its important packaging and weight advantages, combined with potential cost and fuel consumption reductions associated with the two-stoke engine, application of this engine is expected to be very limited in the next decade. The key factors inhibiting its introduction are addressed in the next question.

The incentive to develop this engine is strong for all manufacturers because of its compact size. New styling themes could follow the successful development of the engine. Vehicle weight saving would be significant also, providing an advantage for fuel economy. Because of the inherent advantages, all manufacturers have development efforts underway.

Suppliers of some components such as valves, castings and forgings would be affected by the introduction of this engine. Consider the challenges of engine valve manufacturers as an example. They may see expanded business with more multivalve engines. But if the two-stroke is a hit, their business could deteriorate rapidly.

Because of potential for dramatic impact on a host of automotive systems, developments must be watched closely.

TECH-72 **What are the key factors inhibiting the introduction of two-strokr engines in North American-produced passenger cars? Please circle your response where 1 = extremely significant and 5 = not at all significant.**

Inhibiting Factors	Mean Rating
Emissions	1.7
Noise, vibration, harshness	2.3
Public perception	2.3
Investment	3.4
Durability	2.4
Displacement limitation	3.3
Fuel economy	3.4

Other responses include
Cost of control system: 1.0; lubrication: 2.0; noise: 3.0; starting ease: 1.0.

Selected edited comments

- If the engine works properly, the public will not care.
- It will be tough to convince many Americans to drive cars with "chainsaw engines."

Discussion

Panelists consider all factors to be at least somewhat significant in limiting the future of two-stroke engines. Exhaust emission control is viewed as the most serious challenge, particularly in light of more restrictive future standards.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement with the exception of the areas summarized in the following table.

Inhibiting Factors	Rating	
	Manufacturers	Suppliers
Durability	2.2	2.7
Noise, vibration, harshness	1.9	2.7

Manufacturers view the issues of durability and noise/vibration/harshness as more significant inhibiting factors than suppliers.

Trend from previous Delphi surveys

This question was asked as an open-ended question in the 1992 Delphi VI survey. Panelist responses are summarized below.

Inhibiting Factors	Percent of Panelists
Emissions	80%
Durability	22
Investment	20
Noise, vibration, harshness	19
Fuel economy	13
Public perception	11
Displacement limitation	6

Public perception was ranked as relatively insignificant by 1992 Delphi VI panelists, whereas 1994 Delphi VII panelists rate it as highly significant. One of the selected comments equates this engine to that of a chainsaw. If a two-stroke engine passenger car is developed into a quiet package, public perception must be brought in line with this reality before the vehicle will gain acceptance in the marketplace.

Strategic considerations

Emissions are ranked clearly as the most significant hurdle for this engine. A number of other issues are also rated as very significant. Some of these hurdles may be interconnected such that overcoming or improving one may impact negatively on another. A systems approach will be required to optimize the entire vehicle. The low anticipated application rate in the previous question indicates the extent of the challenges facing the development of this engine for high volume use. Additional strategic considerations are addressed in the previous question.

TECH-73 What percentage of North American-produced passenger cars will incorporate the following advanced engine types in MY 2003?

Engine Types	Median Response	Interquartile Range
Open chamber (DI) diesel	1%	0/4%
Stratified charge spark-ignited	4	1/10
Low-heat rejection engine	1	0/5
Rotary combustion or Wankel	0	0/1
Gas turbine	0	0/1

Selected edited comments

- All have significant limitations in their current forms.
- None of the technologies shown are driven by or necessarily compatible with forthcoming emission standards.
- Stratified charge spark-ignited and low heat rejection engines are unlikely due to NOx.
- The gas turbine will never make it.

Discussion

Open chamber diesel, stratified charge spark-ignited, low-heat rejection, Wankel and gas turbine engines are not expected to receive any meaningful application rate by 2003.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

This forecast is in agreement with the past two Delphi surveys

Strategic considerations

The current gasoline engine is expected to dominate over the next decade. The most likely new entrant with any significant volume is viewed to be the stratified charge spark-ignited engine. In fact, some two-stroke engine designs use an axially stratified combustion process.

Open chamber (D.I.) diesel engines have received much attention in Europe. Our panelists do not see their use in North America in the near future. In fact, diesel engines of any type are not expected to be used in passenger cars produced in North America. (see TECH-70)

Gas turbines have been in the research stage for automotive applications for at least 30 years. They do not appear to be any closer to production application. In fact, it is interesting to note that the gas turbine was viewed to be 10 years away 25 years ago.

Knock and cost limitations probably restrict the low-heat rejection engine to diesels, especially in heavy trucks. This engine in any application is still a long way from becoming commercial.

Our panelists forecast no North American production volume for the rotary combustion engine, in spite of the long-term Japan-based production by Mazda in the RX-7.

Emissions will be a difficult hurdle for alternatives to the current gasoline engine because of tougher federal emission standards as well as very restrictive California requirements. In fact, conventional spark-ignited gasoline engines will be hard pressed to deal with future standards.

TECH-74 What percentage of North American-produced passenger cars with spark-ignited engines will incorporate the following types of fuel-management systems in 1998 and 2003?

Fuel Injection:	Est. 1991*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Throttle body (single point)	23%	10%	2%	10/15%	0/5%
Port or multipoint	77	88	95	85/90	90/98
Direct cylinder injection		0	5	0/1	2/8
Total	100%	98%	102%		

***Source:** Ward's Automotive Reports, December, 1992.

Other responses include:
Bi-fuel with CNG: 1998 - 5 percent 2003 - 25 percent.
CNG (gaseous injection): 1998 - 0 percent 2003 - 2 percent.
Natural gas system: 1998 - 5 percent 2003 - 10 percent.
Port plus: 1998 - 5 percent 2003 - 10 percent.

Selected edited comments

- A natural gas system would apply mostly to fleets.
- Direct cylinder injection is necessary for two-stroke, but this may not happen because of emissions. For four-stroke it is expensive with small if any gain.
- Emission regulations will force out throttle body injection.
- The type of fuel system is independent of the type of fuel. By 2003, even CNG packages will use sequential port fuel injection.

Discussion

Port or multipoint fuel injection is expected to be used in essentially all passenger cars by 2003.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement with the exception of throttle body injection for 2003, where manufacturers forecast zero percent and suppliers forecast 5 percent. The trend for both manufacturers and suppliers is for a significant decline in the use of throttle body injection. Timing is the only question regarding the total elimination of throttle body injection.

Trend from previous Delphi surveys

Fuel-Management Systems	1992	1995			1998	2000		2003
	Delphi III (1984)	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Throttle body	50%	40%	35%	30%	10%	25%	10%	2%
Port (multipoint)	30	18	11	10	88	75	90	95
Carburetion	20	21	30	31	0	0	0	5

The change to multipoint injection has accelerated at a pace greater than that forecast in previous surveys, and is expected to approach 100 percent in the next decade. The 1991 baseline of 77 percent for the 1994 Delphi VII survey is higher than the 1989 Delphi V survey forecast of 75 percent for 2000.

Strategic considerations

The market demand for increased performance and emissions control have driven the move to multipoint fuel injection in passenger cars beyond that expected in previous forecasts. The carburetor is all but gone from the marketplace except for service of older vehicles. Throttle body injection is soon expected to follow the fate of the carburetor as emission standards tighten in the near future. Costs for multipoint injection will continue to decline with the general decline in the cost for computers, electronics and injectors. An interesting development is direct cylinder injection, perhaps patterned to some extent after the Orbital design used for two-stroke engines. Developments of this system should be watched closely, particularly if exhaust emissions can be managed.

TECH-75 What percentage of North American-produced spark-ignited engines for passenger cars will be either supercharged or turbocharged in MYs 1998 and 2003?

Spark-ignited Engines	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Supercharged	0.3%	1%	1%	0.5/1%	0.3/3%
Turbocharged	0.5	1	1	0.5/1	0.5/1

* **Source:** *Ward's Automotive Reports*, December, 1992.

Selected edited comments

- Ceramic turbine wheels will make turbochargers more attractive. Superchargers are too expensive.
- Multivalve seems to have beaten out turbocharging and supercharging.
- Other engine technologies will supersede.

Discussion

The use of turbocharging and supercharging is expected to be almost negligible at 1 percent by the end of the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are generally in agreement.

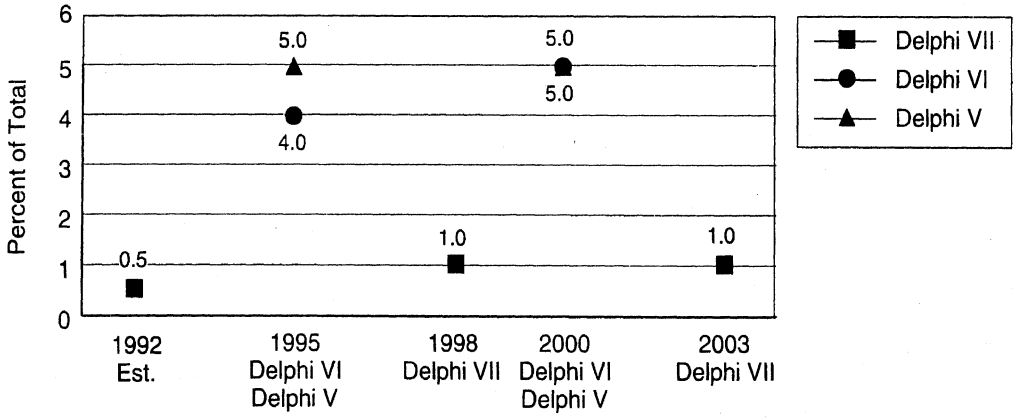
Comparison of Forecast: MKT-35

The Technology and Marketing forecasts are in general agreement.

Trend from previous Delphi surveys

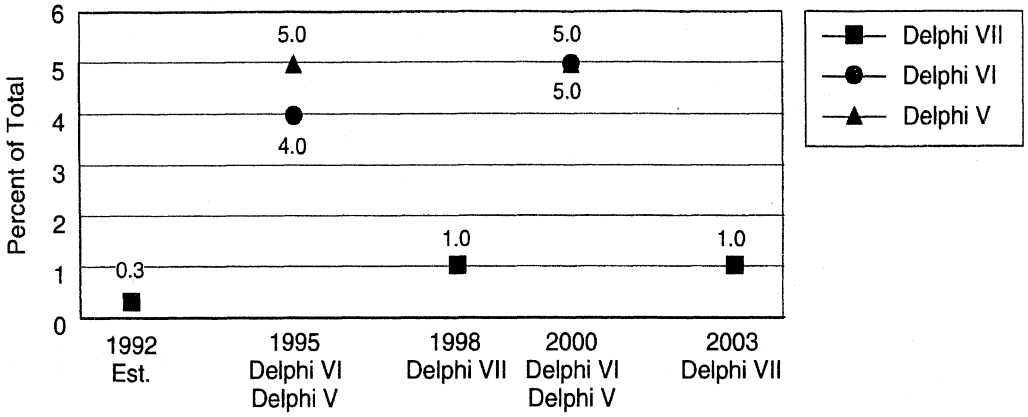
In 1979, Delphi I panelists forecast that by 1990, 25 percent of spark-ignited engines in U.S.-produced light-duty vehicles would be turbocharged. In 1981, Delphi II panelists forecast 10 percent turbocharging in 1990. This 10 percent forecast for 1990 held steady through the 1984 Delphi III and 1987 Delphi IV surveys.

Turbocharged Engine Forecasts
North American Car Production



Panelists in the current survey forecast significantly lower use of turbochargers than those in previous surveys.

Supercharged Engine Forecasts
North American Car Production



Current panelists' forecasts are well below those of previous forecasts for the use of superchargers.

The current survey forecasts limited applications for both turbochargers and superchargers over the next decade. The role of the forced induction system has to a large measure been replaced by multivalve engines. Advances in cam design have also resulted in significant increases in engine power at a much lower cost.

Strategic considerations

The supercharger has the ability to significantly increase low speed torque, which is not possible with multivalve engines or high-lift camshafts. In spite of this advantage, panelists have responded that the application rate is expected to be low. High cost is the likely reason for this response. The supercharger and turbocharger can be added to an engine family at a much lower capital investment level than can a multivalve engine, making them good candidates for niche markets or performance versions of a basic engine.

Tougher emission regulations will also limit the use of turbochargers because of the exhaust heat absorbed by the turbocharger during catalyst warm-up.

CAFE regulations significantly higher than those currently forecast could renew interest in forced induction systems because of the potential to use relatively small engines for a given vehicle application. However, we believe this would not be the preferred technology if CAFE is raised significantly.

TECH-76 What percentage of North American-produced passenger cars with spark-ignited engines will incorporate the following ignition systems in 1998 and 2003?

Ignition Systems	Est. 1991*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Distributorless ignition systems	46%	60%	80%	55/65%	70/100%
Individual cylinder control of ignition	0	5	15	5/5	10/20
Cylinder pressure control of ignition	0	1	5	0/2	2/10
Knock/adaptive control	32	40	60	40/50	50/80
Coil-on-plug designs	n/a	5	10	3/5	10/25

* **Source:** *Ward's Automotive Yearbook*, 1992.

Selected edited comments

- An energy level of 40/50 MJ will probably be required at the plug.
- With knock/adaptive control, some feedback to the operator is necessary on whether the fuel being used causes enough average retard to substantially degrade fuel economy and/or power.

Discussion

Distributorless ignition systems and knock/adaptive control are expected to be used in most engines by 2003. The other technologies—including individual cylinder control of ignition, cylinder pressure control of ignition and coil-on-plug designs—are expected to see limited application.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Ignition Systems	1992	1995			1998	2000		2003
	Delphi III (1984)	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Distributorless ignition systems	50%	40%	50%	60%	75%	75%	80%	2%
Individual cylinder control of ignition	20	40	40	5	75	60	15	—
Closed-loop timing	—	10	—	1	25	—	5	—
Knock/adaptive control	55	30	40	40	60	65	60	95
Coil-on-plug designs	—	5	5	5	15	10	10	5

Results of the current survey compare well with those of past surveys with the exception of individual cylinder control of ignition. The current survey projects only 5 percent application in 1998 and 10 percent in 2003 as compared to 40 percent in 1995 and 60-75 percent in 2000 from past surveys. The source of this difference is unclear. It may be related to patent issues noted by respondents to the last survey or the technology not meeting expectations.

Strategic considerations

Distributorless ignition systems are projected to continue to increase in use through the decade, and would appear to be headed toward near 100 percent use in the following decade. The ability to eliminate the variation in spark setting will continue to increase in importance with increased emission requirements. Reliability is also enhanced.

Knock/adaptive control will be on the majority of engines by 2003. This technology allows the optimum performance to be obtained for a wide range of fuel octanes, and compensates for

cylinder-to-cylinder and engine-to-engine variation in compression ratio.

Individual cylinder control including cylinder pressure control of ignition has emission benefits. But apparently the cost cannot be justified by the benefit derived, at least with the present and expected future technology. Of course, new developments could alter this forecast markedly.

Coil-on-plug designs are just beginning to be used. Their virtues are still being evaluated. The cost benefits issue is particularly crucial and must be resolved if use of this technology is to expand.

TECH-77 What percentage of North American-produced passenger car engines will incorporate the following number of valves per cylinder in 1998 and 2003?

Valve Configurations	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Two valves per cylinder	87%	80%	60%	75/80%	50/67%
Three valves per cylinder	0.1	0.5	1	0/1	0/2
Four valves per cylinder	12.9	20	35	19/25	30/48
Five valves per cylinder	0	0	0	0/0	0/1

* **Source:** *Ward's Automotive Yearbook,* 1992.

Selected edited comments

- Cost is still a big issue.

Discussion

Two-valve-per-cylinder engines are expected to be used in the majority of passenger car engines through 2003. The penetration of designs with four valves per cylinder is expected to increase to about one third of all applications, however.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

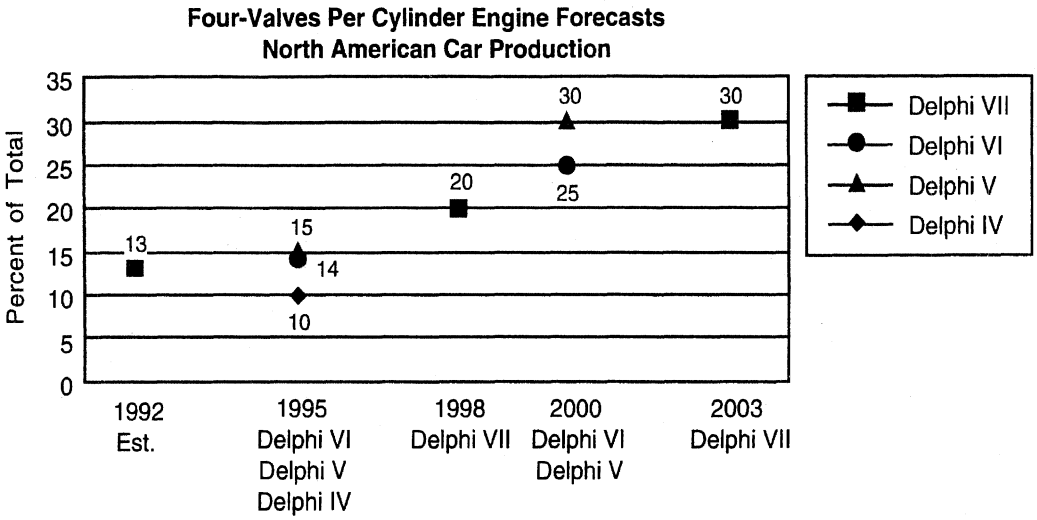
Comparison of forecast: MKT-40

The forecast for increased use of multivalve engines in the future is similar between Technology and Marketing panelists.

Trend from previous Delphi surveys

Valve Configurations	1995			1998	2000		2003
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Two valves per cylinder	70%	80%	76%	80%	60%	65%	60%
Three valves per cylinder	20	5	5	0.5	10	5	1
Four valves per cylinder	10	15	14	20	30	25	35
Five valves per cylinder	—	—	5	0	—	5	0

The current survey projects essentially no application of engines with three or five valves per cylinder. This is in contrast to previous surveys that projected a 5-10 percent application of these configurations. The current survey projects a split between two and four valves per cylinder, with four valves per cylinder increasing throughout the decade and two valves per cylinder decreasing.



The current survey is in good agreement with previous surveys with regard to the application rate of engines with four valves per cylinder.

Strategic considerations

The current and past surveys project an increase in the application of engines with four valves per cylinder, but engines with two valves per cylinder are expected to dominate by a ratio of 2.5:1. In spite of the increased power available from four-valve engines, cost and packaging challenges will limit their use. Advances in increasing power in engines with two valves per cylinder will also keep this configuration in a predominant role for some time to come. To increase efficiency, combustion chamber shape can be optimized with a four-valve-per-cylinder engine. However, the increased parasitics from the valvetrain may more than offset these benefits.

The balance between two- and four-valve-per-cylinder engines will continue to be influenced by fuel economy, cost, market demand for performance, packaging considerations and capital constraints. The customer focus on value is a critical factor today. The substantial cost penalty of four-valve designs, and less pronounced relative advantages over two-valve configurations as the precision of these low tech engines has been greatly improved, assures a continuing strong role for two-valve heads. A key challenge for manufacturers is to accurately read customer expectations for engines.

TECH-78 What percentage of North American-produced passenger car engines will utilize the following valvetrain configuration in 1998 and 2003?

Valve Configurations	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Push rod	55%	49%	35%	40/50%	20/40%
Single overhead cam	32	35	40	33/40	35/50
Dual overhead cam	13	15	20	15/20	16/30
No cam (electromagnetic actuation)	0	0	1	0/0	0/3

***Source:** *Ward's Automotive Reports*, December, 1992.

Selected edited comments

- Changes will correlate with introduction of new (or major redesign) engines.
- Electromagnetics need lightweight material and are energy inefficient. Other methods may happen, particularly pneumatics.
- Push rods will be used only on "V" configuration to reduce valve train costs.

Discussion

Single and dual overhead cam engines are expected to see increased penetration in the next decade, with a decline in the pushrod configuration. However, push rod designs are expected to still be used in a significant fraction, 35 percent by 2003. Applications with no camshaft (individually actuated valves) are expected to be negligible.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

Valvetrain Configurations	1995			1998	2000		2003
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Push rod	30%	60%	45%	49%	60%	30%	35%
Single overhead camshaft	50	30	45	35	30	50	40
Dual overhead camshaft	20	10	10	15	10	18	20
No camshaft (e.g., electromagnetic)	—	—	0	0	—	2	1

Agreement between surveys is good for dual overhead camshafts, but there is significant variability relative to the balance of push rod versus single overhead camshaft engines.

For push rod engine, the current survey is in the mid-range of previous surveys, but there is considerable variation between surveys.

Strategic considerations

The variance between this and previous surveys with regard to push rod engines is an indication of the uncertainty in this area. As stated in the previous question, advances in push rod engines in the recent past have put into question the need to move to overhead cam or multivalve engines. Still, the trend to overhead cam designs is strong. There is also a question as to the market value of technology if the customer cannot perceive a benefit. It is not clear that the customer can determine the benefit derived from the move to overhead camshafts. Capital availability will also influence this shift in technology.

Dual overhead cams will continue to lag in the market because of cost, weight, packaging constraints, fuel economy and capital constraints. The third comment relative to overhead cams in in-line vs. "V" engines is pertinent.

TECH-79 What percentage of engines produced in North America by traditional domestic manufacturers will employ the following valvetrain technologies in 1998 and 2003?

Valvetrain Advances	Median Response		Interquartile Range	
	1998	2003	1998	2003
Variable timing control	5%	20%	3/10%	10/25%
Variable lift control	1	10	0/5	2/20

Selected edited comments

- These two features will be interrelated.
- This survey should check on lighter and faster acting valves. That's particularly important for intake valves closing in midstroke to reduce throttling losses at part load.

Discussion

Significant application of variable timing control and variable lift control is expected at 20 percent and 10 percent respectively by 2003.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Valvetrain Advances	1995			1998	2000		2003
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Variable timing control	10%	5%	2%	5%	10%	10%	20%
Variable lift control	—	1	1	1	5	5	10

Results for variable timing control from the current survey are in line with past surveys. Results for variable lift control from the current survey generally agree with previous surveys.

Strategic considerations

The large interquartile range for variable lift control suggests considerable uncertainty with regard to this technology. However, both variable timing control and variable lift control could see significant application by the end of the decade, according to current and past panelists.

Both of these features will be used to enhance exhaust emission control and improve fuel economy and performance. The application rate will depend on future developments in cost and proven reliability and durability.

Mechanical devices for controlling valve timing have been available for several years, but have not seen significant use because of cost and complexity. It is likely that any large-scale introduction of these features will be in conjunction with electromagnetic devices. The challenges are significant in this area, as the force required to overcome the valve spring and valve inertia is great. Lightweight valves and valvetrains will play a part in the successful application of these devices.

TECH-80 What percentage of passenger car engines produced in North America in 1998 and 2003 will incorporate aluminum or magnesium cylinder heads and/or blocks?

Engine Material	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Aluminum heads	55%	65%	80%	60/70%	70/90%
Aluminum blocks	14	20	35	18/25	25/50
Magnesium heads	0	0	0	0/1	0/2
Magnesium blocks	0	0	0	0/0	0/1

***Source:** *Ward's Automotive Reports*, December, 1992.

Selected edited comments

- All engine programs in the future will strongly consider aluminum blocks at $1/pound cost.
- Composite blocks could be less than 2-3 percent.
- Coolant compatibility is a roadblock to increased use of magnesium heads and blocks.
- Trucks will continue to use iron blocks, but will also increase usage of aluminum heads.

Discussion

Aluminum usage in engine heads and blocks is expected to increase significantly. Magnesium is not forecast to be used in either heads or blocks in the next decade.

Manufacturer/supplier comparison

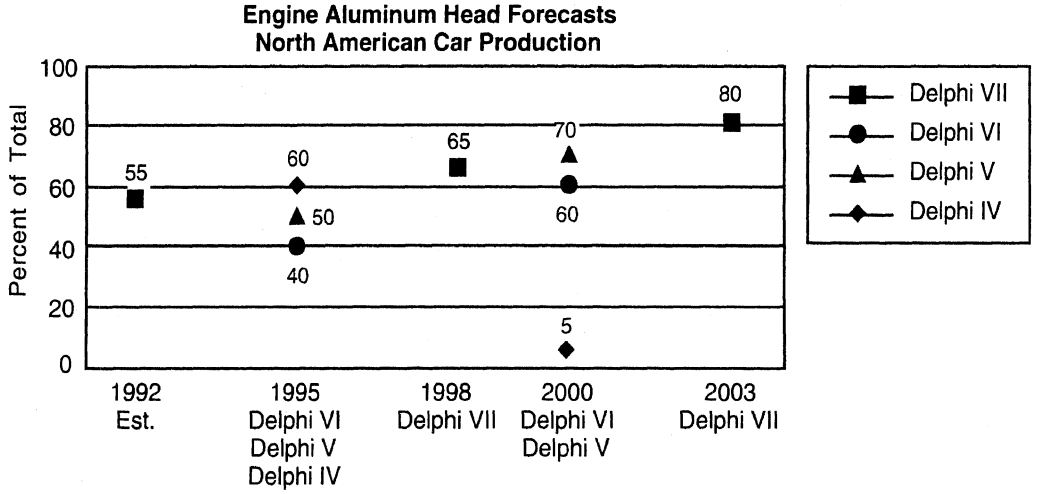
Manufacturers and suppliers are in agreement.

Comparison of Forecasts: MAT-22

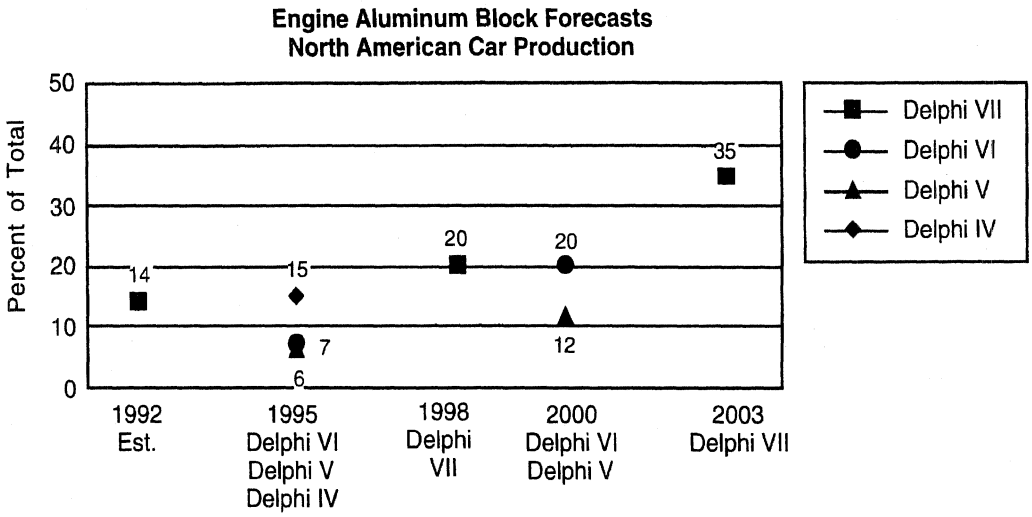
Responses of the Technology and Materials panels are in general agreement with the exception of the forecast for aluminum heads for 1998. In this case, the Technology and Materials panels forecast 65 percent and 55 percent respectively. This difference follows a general trend that Materials panelists forecast less rapid changes in materials compared to the Technology panelists, perhaps as a result of the closer association to materials for the Materials panelists.

Trend from previous Delphi surveys

Magnesium was added in this survey, and it is clear that there is no interest in this material application at this time.



This survey is in agreement with, but on the high side of, previous surveys with regard to aluminum heads.



The current forecast for application rate of aluminum blocks is modestly higher than previous forecasts. This likely reflects the growing concern for CAFE and consequent need for weight reduction.

Strategic considerations

Current and past panelists forecast an increasing role for aluminum in cylinder heads and cylinder blocks. The obvious incentive for this move is the significant weight savings as compared to cast iron. Advancements in weight reduction with cast iron through thin wall casting have reduced the advantage that aluminum has in this area, but the differential is still considerable. The shift to aluminum will undoubtedly continue with increased pressure on fuel economy.

The weight advantage of aluminum in engines is greater than just the differential in weights between cast iron and aluminum. A lighter engine can use a lighter cradle, mounting system and suspension components. These advantages will not be realized with the direct substitution of aluminum for cast iron in a given vehicle, but will be realized with new vehicles or redesigns of current vehicles. On the negative side, manufacturers that use aluminum in heads and blocks and achieve quiet vehicles generally use cast iron accessory mounting brackets to reduce noise and vibration. Cast iron accessory mounting brackets are of benefit for noise reduction, however, even with cast iron heads and blocks. The internal damping capabilities of cast iron are significant.

Increased noise has been considered a negative for aluminum in the past, but the Japanese manufacturers have proven that it is possible to use aluminum in engine blocks and heads and still have a very quiet vehicle. A systems approach is required to achieve such excellent results.

A past concern expressed with aluminum cylinder blocks is the sensitivity to overheating. This matter has been addressed in a number of ways, including more sophisticated over-temperature monitoring systems. The large number of engines using aluminum today have proven that this is a manageable situation.

As fuel economy demands increase, and the value of a pound of weight savings increases (TECH-49), more aluminum will certainly be used in cylinder heads and blocks.

TECH-81 What percentage of North American-produced passenger car engines will incorporate the following technical features in 1998 and 2003?

Advanced Engine Features	Est. 1991*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Balance shaft (% of four-cylinder engines)	17%	20%	25%	20/25%	25/40%
Balance shaft (% of six-cylinder engines)	30	35	40	30/40	35/50
Fast-burn combustion chamber	n/a	40	75	30/50	60/80
Hollow camshaft	n/a	10	15	5/10	10/25
Powdered metal cam and gears	n/a	3	10	2/5	5/15
Roller lifters	45	55	70	50/60	60/75
Twin spark plugs per cylinder	1	1	2	1/2	1/5

* **Source:** *Ward's Automotive Yearbook*, 1992.

Selected edited comments

- "Fast" is a relative term. How fast must you be to be rated fast? A balance of emissions, dilution tolerance, knock limited torque and noise (pressure rise rate) will determine burn rate.
- Hollow camshafts could be integrated or used as part of a variable timing scheme.
- Roller lifters will be reduced with DOHC and SOHC engines.
- Since balance shafts are not needed in L-6 or 60-degree V-6, only the portion designed as 90-degree V-6 will incorporate them. Since noise, vibration and harshness are big customer requirements, all 90-degree V-6 passenger car engines will use balance shafts. This will be just part of the package—power, tooling, modular and trade-off considerations.
- Specific technical features are secondary to major powertrain drivers: less friction, less noise and vibration, less mass, lower engine out emissions, and, in some cases, higher specific output.

Discussion

Panelists believe that most engines will have fast-burn combustion chambers and roller lifters by 2003. In the same timeframe, balance shafts are expected to be used in almost half of all six-cylinder engines. The other features—including hollow camshaft, powdered metal cam and gears, and twin spark plugs per cylinder—are forecast to see increased, but still low, penetration.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Comparison of Forecast: MAT-24

Powdered metal camshaft lobes are addressed in the Materials survey. Forecast penetration is higher than that forecast in the Technology survey for cam and gears. Materials survey results are shown below.

Materials Survey Results Powdered Metal Camshaft Lobes Penetration		
Current Est.	1998	2003
2%	15%	20%

Trend from previous Delphi surveys

Results from previous surveys are summarized in the following table:

Technical Features	1995			1998	2000		2003
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Balance shaft (% of four-cylinder engines)	25%	20%	25%	20%	40%	30%	25%
Balance shaft (% of six-cylinder engines)	10	20	20	35	20	30	40
Fast-burn combustion chamber	75	65	70	40	80	80	75
Hollow camshaft	15	10	10	10	20	15	15
Powdered metal cam and gears	20	10	10	3	20	20	10
Roller lifters	50	40	50	55	60	70	70
Twin spark plugs per cylinder	5	2	2	1	4	2	2

Balance shaft, four-cylinder engines: The forecast for the 2000-2003 time frame has decreased in each of the past three surveys. 1998 estimates are in general agreement with past surveys.

Balance shaft, six-cylinder engines: The forecast for the 1995-2003 time frame has increased in each of the past three surveys.

Fast-burn combustion chamber: The current forecast for 1998 is significantly below previous estimates for 1995. The forecast for 2003 is in general agreement with past estimates for 2000. Therefore, the current forecast indicates delayed application at high levels but increasing to 75 percent in 2003.

Hollow camshaft: The forecast for the 2000-2003 time frame is in the same range in the 1992 Delphi VI and 1994 Delphi VII surveys. The estimates for 1995 and 1998 have been the same for the past three surveys.

Powdered metal cam and gears: Current estimates are below past estimates.

Roller lifters: Current and past estimates are in general agreement.

Twin spark plugs per cylinder: Current and past estimates are in general agreement for low penetration.

Strategic considerations

Balance shaft, four-cylinder engines: The forecast penetration of this feature for the end of the decade has declined in each of the past three surveys. Negative aspects of this feature which may be receiving attention and contributing to this decline are cost, weight, fuel economy loss because of increased parasitic load, noise and possibly poor durability. Also, as engines are downsized, the need for balance shafts is reduced. Reductions in reciprocating mass also reduce the need for balance shafts. Finally, four-cylinder engines are generally installed in downscale vehicles, where the noise and vibration reduction benefits may not be considered an important value by the customer.

Balance shaft, six-cylinder engines: The current and past surveys show an increasing move toward balance shafts in six-cylinder engines. As noted in one of the comments, balance shafts are only needed on 90-degree V-6 engines. Note that the past and current survey application rates may include all 90-degree V-6 engines by the end of the decade.

Fast burn combustion chamber: The reduced expectation for fast burn in the 1995-98 time frame in this survey is somewhat of a surprise. Nevertheless, the long-term expectation is similar to past surveys. This design will be included in most engines by the end of the decade. As noted in one comment, the definition of fast burn is hardly clear. Generally, all engines today have faster burn designs than their predecessors.

Hollow camshaft: Expectations for hollow camshafts are similar to past surveys.

Powdered metal cam and gears: Current panelists have reduced expectations for the use of powdered metal cam and gears. This material use will see only limited application in the next decade.

Roller lifters: Current and past panelists predict that roller lifters will be included in the majority of engines by the end of the decade. The fuel economy benefit from this feature is significant. Cost is an obvious limiting factor. One of the panelists raised a pertinent comment that roller lifters will not generally be used with DOHC and SOHC engines in the future.

Twin spark plugs per cylinder: This feature has shown limited benefit for its cost and added complexity. The projected use, as a result, is negligible.

TECH-82 What percentage of North American-produced passenger cars will use lean burn technology with and without a NOx catalyst by MY 2003?

Lean Burn Technology	Median Response			Interquartile Range		
	<2500 lb	2500-3500 lb	>3500 lb	<2500 lb	2500-3500 lb	>3500 lb
With NO_X catalyst to meet:						
Federal standards	5%	10%	10%	0/20%	0/20%	0/20%
California standards	10	10	10	0/20	0/30	0/40
Without NO_X catalyst to meet:						
Federal standards	0	0	0	0/0	0/0	0/0
California standards	0	0	0	0/0	0/0	0/0

Selected edited comments

- It will not work at LEV levels.
- Lean burn technology will use a catalyst to recalibrate to improve fuel economy.
- There is a major question on lean-burn effectiveness.

Discussion

Use of lean burn technology with a NOx catalyst is expected in approximately 10 percent of North American-produced passenger cars by 2003.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Lean Burn Technology	1995			2000		2003
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
	20%	5%	5%	15%	8%	10%

Results of this survey are in general agreement with past surveys, with the exception of the 1987 Delphi IV survey which predicted a significantly higher application rate by 1995.

Strategic considerations

Lean burn technology application is dependent on the development of a lean NOx catalyst. There is considerable work directed toward the development of such a catalyst, and most panelists believe this work will be successful in the next decade to allow limited application.

Lean burn technology offers the potential for fuel economy improvement because of the lower throttling losses associated with running at very lean mixtures and the generally better thermodynamic properties of the working fluid. The complexity of the problem of lean mixture NOx reduction is indeed formidable since the combustion exhaust gases contain oxygen. This supports oxidation reactions while breaking NOx down to its basic elements and requires a reducing environment (no oxygen and some reducing compound such as CO or H_2).

TECH-83 What percentage of catalytic converters will be electrically or fuel heated to meet federal and California standards?

Catalytic Converter Type	Median Response				Interquartile Range			
	To Meet *Federal Standards*		To Meet *California Standards*		To Meet *Federal Standards*		To Meet *California Standards*	
	1998	2003	1998	2003	1998	2003	1998	2003
Electric	1%	5%	10%	20%	0/5%	2/20%	2/10%	10/40%
Fuel	3	10	5	20	0/5	0/20	0/10	5/30
Unheated	95	80	85	60	90/100	60/95	70/94	40/80
Total	99%	95%	100%	100%				

Selected edited comments

- Assume federal and California will converge by 2003.
- Competing technologies may minimize the need for preheated catalyst.
- Federal standards are locked in by statute through 2003.

Discussion

Nearly half of all catalytic converters used to meet California standards are expected to use preheating by 2003. In contrast, only 15 percent of the converters used to meet federal standards are expected to be heated.

Manufacturer/supplier comparisons

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi Survey.

Strategic considerations

Application of either electric or fuel heated catalytic converters would add significant cost, mass and complexity to the vehicle. Electric heat may influence the size of the battery and alternator required. Panelists forecast a need for heated converters to meet California standards in nearly half of vehicles sold there. This would also include vehicles sold in states that choose to adopt the more stringent California standards.

The choice between electric and fuel heating of the converter appears to be evenly split at this time for the 2003 timeframe. Because of the added cost and complexity of these systems and low perceived value on the part of customers, manufacturers will work diligently to find other ways to achieve required emission control.

TECH-84 What new components, fuels or technologies will be introduced in the next decade for North American-produced passenger cars to help meet new emission standards?

New Components/Fuels/Technologies	Percent of panelists
Catalytic converters	**17%**
Heated catalyst	7%
Start-up catalyst with bypass	4
Lean NO_X catalyst	3
Catalyst bypass; Metal substrate catalytic converter; Heat battery (Schnotz)	1% each
Fuels	**17%**
Fuel improvements	11
Alternative fuel technology	4
CNG; Junk fuel recognition and control	1% each
Electronics	**9%**
Smart sensors for rpm, cylinder pressure and knock control	4%
Advanced on-board diagnostics	3
More sophisticated ECM's; Real time control of fuel and spark using adaptive technology and 32-bit microprocessor	1% each
Fuel controls	**7%**
Improved A/F control	3%
Improved injectors	3
Variable induction systems	1
Valvetrain	**4%**
Closed-loop cam timing and lift; Electronically controlled valve actuation; Lighter and faster acting valves; Variable valve timing	1 % each
Exhaust heat conservation	**3%**
Dual wall exhaust pipes	2%
Insulated exhaust ports (ceramic liners)	1
Ignition	**3%**
Advanced high energy ignition; Faster burn ignition; New types of spark plugs	1% each
Other	**11%**
EHC	3%
DI diesel—four-valve; Direct injection; Electric vehicle; Hybrid; Revised coolant flow schemes; Variable compression ratio; Variable fuel pressure; Very low idle speed	1% each

Discussion

Panelists anticipate introduction of a number of interesting components and technologies affecting many areas of the vehicle to help meet new emission standards. These areas include the basic engine, engine controls, electronics, fuels and exhaust systems.

Trend from previous Delphi surveys

This question was asked in the 1992 Delphi VI survey. The areas receiving the most responses were:

Delphi VI Engine Changes	Percent of panelists
Improved fuel management	35%
Multivalve	21
Displacement reduction	16
Variable valve timing	16
Increased electronic controls	15
Electric car	15
Flexible fuel capability	13
Friction reduction	13
Lightweight materials	10

Responses have changed substantially between the 1992 and 1994 surveys. This may be a result of recent developments in fuels and catalytic converters. Current panelists rarely mention basic engine design features such as multivalve, whereas they were mentioned frequently in the 1992 survey. Again, this may be a result of recent information regarding these features.

Strategic considerations

Many changes in engines and vehicles may be required in the next decade to meet more restrictive emission and fuel economy standards. These changes will require significant capital investment and substantial skilled human resources. Vehicle cost will also increase as a result of new hardware. This increase in vehicle cost may affect the number of vehicles sold and the product mix in a market that is increasingly sensitive to value and affordability.

All manufacturers must address these changes. The manufacturer that is able to meet the new requirements in the most cost-effective manner will be at a competitive advantage in the marketplace.

A point of general importance is a move to deal with the reality of a worldwide shortage of capital and critically skilled people. Furthermore, it appears to be becoming politically desirable to use taxpayers' money more efficiently. Questions are being raised with regard to the cost/benefit aspects of public policy. A particularly crucial public policy confrontation is occurring in California as environmental and economic forces are challenging one another. If reason prevails (supported by sound risk analysis and growing partnership between government and industry), the future direction of regulation could be altered. This could result in moderation of regulatory demands, and therefore the role of many advanced or new technologies in engines as well as in other areas of the vehicle.

TECH-85 What percentage of North American-produced passenger car engines will incorporate components that are plastic-based in 1998 and 2003? Please provide your estimate for current vehicles.

Plastic-Based Components	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
Connecting rods	0%	0%	0%	0/0%	0/0%	0/1%
Intake manifold	5	15	30	5/5	10/20	25/50
Oil pan	1	5	15	1/2	5/10	10/25
Piston skirts	0	0	0.8	0/0	0/1	0/2
Rocker arms	0	0	0	0/0	0/1	0/2
Valve covers	5	15	40	3/5	15/20	30/50
Throttle bodies	0	5	10	0/1	2/10	5/30

Other responses include:
Block/heads: Current estimate: zero percent; 1998: zero percent; 2003: 5 percent.

Shaft and stem seals: Current estimate: 100 percent; 1998: 100 percent; 2003: 100 percent.

Selected edited comment

- Plastic-based oil pans and valve covers will increase in usage. Plastic-based rocker arms will increase by 1998 and decrease by 2003.

Discussion

The use of plastic-based materials for intake manifolds, valve covers, and oil pans is expected to increase from a modest level currently to an important fraction of the total, 15-40 percent by 2003. It should be noted, however, that there is considerable uncertainty about plastic-based oil pans.

As noted in TECH-50 and 51, the issue of recycling may be an important factor in the selection of future materials. Plastics present a particularly significant challenge in this regard. Nevertheless, panelists believe that the use of plastics will increase substantially for many specific components.

Plastic based materials are not expected to be used in connecting rods, piston skirts or rocker arms in the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Comparison of forecast: MAT-20

Technology and Materials panelists are in general agreement.

Trend from previous Delphi surveys

The current and past surveys are in general agreement.

Strategic considerations

The shift to plastic-based materials for intake manifolds, valve covers and oil pans may have a significant impact on suppliers as tooling and investment shifts away from the stamping or casting of aluminum or steel. This is particularly important since these material technologies are typically not used by the same supplier.

TECH-86 What percentage of spark-ignited engines in North American-produced passenger cars will use these ceramic engine components in 1998 and 2003?

Ceramic Engine Components	Median Response		Interquartile Range	
	1998	2003	1998	2003
Exhaust manifold/port liner	1%	5%	0/1%	2/10%
Piston crown	0	2	0/1	0/5
Piston rings, coating	0	2	0/2	0/10
Seals	5	10	2/10	7/25
Turbocharger turbine/rotor (based on percent of engines equipped with turbochargers)	10	30	5/10	20/40
Valvetrain components (includes valves, inserts, guide seats, tappets, cam, etc.)	2	10	1/3	5/12

Other responses include:

Spark plug insulators: 1998: 100 percent; 2003: 100 percent.

Wrist pins: 1998: 5 percent; 2003: 50 percent.

Selected edited comments

- If ceramic valvetrain components become possible it will be all or nothing. Ceramic exhaust manifolds/port liners and piston crowns are of more interest in diesels with turbochargers.
- There will be a gradual movement to ceramic engine parts as cost comes down and durability becomes proven.
- Water pump seals are typically ceramic now.

Discussion

With the exception of spark plugs, ceramic materials in engine components are not expected to be used in a significant percentage of vehicles in the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are generally in agreement.

Comparison of forecast: MAT-21a and MAT-21b

Forecasts for the Technology and Materials surveys are in agreement except for those compared in the following table.

Ceramic Engine Components	Median Response			
	1998		2003	
	TECH	MAT	TECH	MAT
Piston crown	0%	5%	2%	10%
Piston rings, coating	0	5	2	10
Seals	5	1	10	2

The technology panelists forecast higher use of ceramics on seals and lower use on piston crowns and piston rings than the materials panelists.

Trend from previous Delphi surveys

The results from the two previous surveys are summarized in the following table.

Ceramic Engine Components	1995		1998	2000		2003
	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Exhaust manifold/port liner	3%	1%	1%	10%	5%	5%
Piston crown	2	0	0	8	2	2
Piston rings, coating	0	0	0	0	5	2
Seals	2	2	5	10	5	10
Turbocharger turbine/rotor (based on percent of engines equipped with turbochargers)	5	10	10	15	20	30
Valvetrain components (includes valves, inserts, guide seats, tappets, cam, etc.)	2	2	2	10	10	10

Results for the current survey are in general agreement with the past two surveys.

Strategic considerations

As in the previous two surveys, there appears to be limited enthusiasm for the application of ceramics internal to the engine. Only very modest applications are forecast for the next 10 years, with the exception of turbocharger turbine/rotor. However, since turbochargers are forecast to have low usage (Ref. TECH-75), even that ceramic component would only be on a small fraction of total engines produced.

Durability of any component internal to the engine is critical with ceramics, as a failure of that component will likely cause catastrophic failure of the engine. This includes exhaust components such as port and manifold liners, as elements in the exhaust can be ingested into the cylinder during the valve overlap portion of the cycle. Only as this durability is proven will ceramics be used to any significant extent. Of course, cost/manufacturing problems are still a major concern. Still, developments must be watched closely. A key breakthrough could come at any time and cause a significant dislocation in some key components.

TECH-87 What percentage of North American-produced passenger cars will have active or semi-active engine mounts in 1998 and 2003?

Active/Semi-active Engine Mounts	Median Response		Interquartile Range	
	1998	2003	1998	2003
	5%	10%	2/5%	5/15%

No comments

Discussion

Panelists suggest a growing interest in active or semi-active engine mounts, but application rates in the next decade are expected to remain low. Cost will initially limit application to premium vehicles.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey. The results are similar for the two surveys.

Strategic considerations

The application of this technology will provide another tool for affording increased customer satisfaction through increased engine isolation. Of course, a systems approach which addresses the balance between competing technologies aimed at increasing customer satisfaction should be used. For some, this might lead to active or semi-active mounts whereas for others, different technologies might be used. Some engines have greater need for special mounting technology than others.

TECH-88 Please estimate the mix of transmissions for passenger cars manufactured in North America in MYs 1998 and 2003. Total manual plus total automatic should equal 100%.

Transmission Mix	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Manual					
Four-speed	0.3	0%	0%	0/.2%	0/0%
Five-speed	11.0	10	10	10/10	9/10
Six-speed	0.1	1	1	0.2/1	1/2
Total manual	11.4	11	11	10/11	10/12
Automatic					
Three-speed	32%	25%	10%	20/25%	3/15%
Four-speed	57	63	65	60/68	60/70
Five-speed	0	3	10	1/5	3/13
Six-speed	n/a	0	0	0/0	0/1
Continuously variable (CVT)	0	0	1	0/0	0/1
Total automatic	89%	91%	86%	88/90	87/90
Total	100%	102%	97%		

*Source: *Ward's Automotive Reports*, December 1992.

Selected edited comments

- Automatic "manuals" will result in improved fuel economy.
- CAFE standards will result in downsized vehicles which will use manual transmissions. The trend should not surprise anyone.
- Consider the attraction of an electronically-controlled automatic that does not incorporate a hydrokinetic element with the associated losses.
- I think people are underestimating the market penetration of the small/cheap segment and the high use of three-speed automatics. I expect penetration to be 50 percent in 1998 and 40 percent in 2003.
- I think the increase in manuals (due to CAFE) will be modest.
- Manuals will become more automatic, and some automatics will offer more manual control. Five-speed automatics will start to emerge with downsized, high-tech engines—especially as CAFE drives the use of smaller displacement engines in the larger vehicles.
- With electronic knowledge growing, a continuously variable transmission should be the design of the day.

Discussion

The five-speed transmission is expected to be the only manual transmission with any significant volume in the next decade. The three-speed automatic transmission is forecast to continue its decline, but still should be used in significant numbers (10 percent) by the end of the decade. Five-speed automatic transmissions are expected to see modest application levels in upscale vehicles.

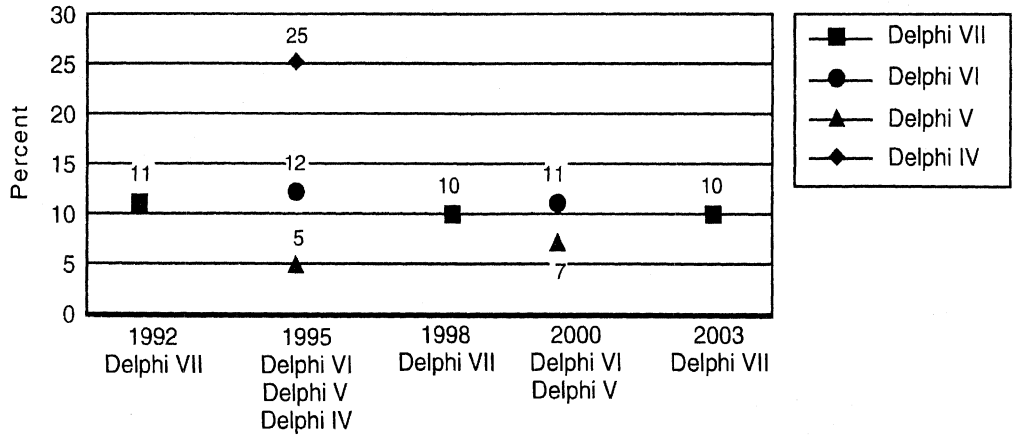
Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

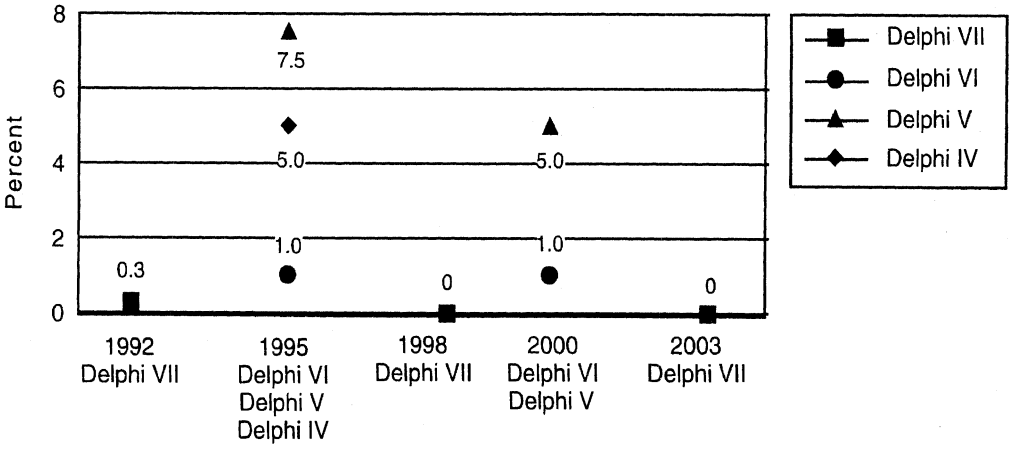
The total mix between manual and automatic transmissions has been similar for this and the previous two surveys. There has been a shift between four- and five-speed manual and three- and four-speed automatic transmissions, however. These shifts are illustrated in the graphs below.

Five Speed Manual Transmission Forecast

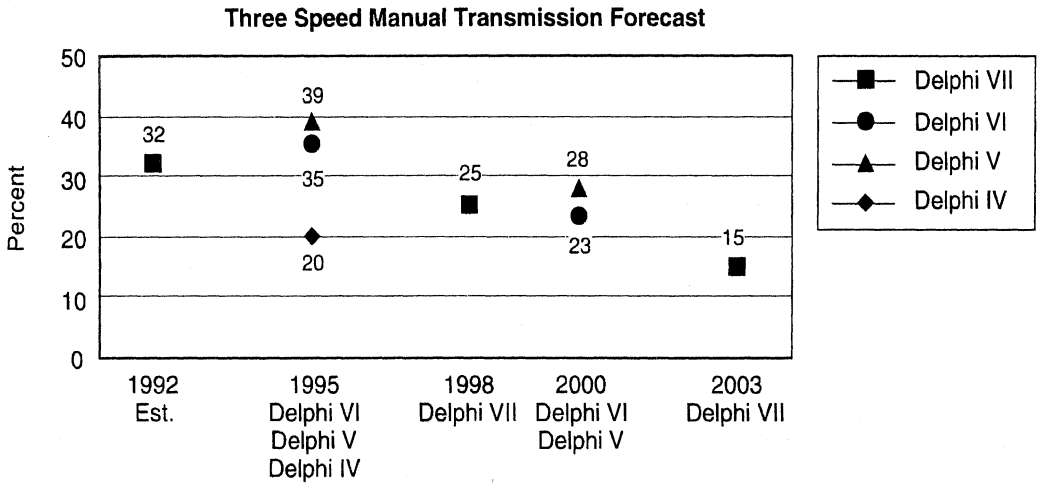


This survey agrees with the previous survey, the 1992 Delphi VI study, with regard to five-speed manual transmissions, but is somewhat higher than the 1989 Delphi V survey, and significantly lower than the forecast in the 1987 Delphi IV survey. The interquartile range in the current survey indicates little uncertainty or difference of opinion.

Four Speed Manual Transmission Forecast



The forecast volume for four-speed manual transmissions has decreased with the last three surveys.



Results of the current survey fall between the previous two surveys and the 1987 Delphi IV survey. The forecast for the time period 2000-2003 appears to be converging on a narrow range.

Strategic considerations

The low cost of the three-speed automatic transmission is an important attraction, but fuel economy requirements and the customer demand for performance and four-speed transmissions may drive a decline in market share. This trend toward more costly components, as discussed in previous questions, may have a negative effect on total vehicle sales or cause a shift to smaller vehicles, as vehicles become less affordable for the average consumer.

A key issue is the integration of the engine/transmission as a system. With electronic control, and an improved ability to control engine variables, it may be possible to achieve performance improvements without increasing the number of transmission gear ratios. The cost/benefit trade-off is crucial in these days of value and affordability concerns.

TECH-89 What percentage of North American-produced passenger cars with front engine, front drive will have fore-aft or transverse engine orientation in 1998 and 2003?

Engine Orientation	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Fore-aft	0%	3%	6%	1/10%	3/15%
Transverse	100	97	94	95/99	85/97

Selected edited comments

- Fore-aft improves cab forward.
- LH cars will become popular.
- Longitudinal FWD will increase for a number of reasons, including styling/proportions, SLA front suspension compatibility, better PUP converter/equal length exhaust, reduced exhaust manifold noise to front of dash transmission and improved front of dash thermal environment.

Discussion

Fore-aft mounting of the engine is expected to have limited application in the next decade, despite the success of Chryslers LH products.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi study.

Strategic considerations

The Chrysler LH platform has introduced a fore-aft engine mounting in a popular domestic passenger car. The attributes of this configuration are well noted in the selected comments. Panelists project only a modest shift to fore-aft mounting in the next decade, however. It is likely that the transmission tooling cost for this change is a significant prohibiting factor. The voice of the customer will, of course, be a significant factor as well in this decision.

Additional comments relative to this subject are found in the questions regarding cab forward: TECH-42 and TECH-43.

TECH-90 What percentage of North American-produced passenger cars will use the following drivetrain configurations in 1998 and 2003?

Drivetrain Configurations	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Front engine, front drive	87%	88%	89%	86/90%	85/91%
Front engine, rear drive	13	10	10	10/12	8/11
Front engine, four-wheel drive	<1	1	1	1/1.5	1/4
Total	100%	99%	100%		

*Source: *Ward's Automotive Reports*, December, 1992.

Selected edited comments

- Electronic traction control will make rear drive more acceptable in northern climates.
- Mass/fuel economy penalty will restrain 4WD market.
- Traction control will make RWD more preferred, but it will be slow.

Discussion

Front engine, front drive vehicles are expected to continue their domination in passenger cars over the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

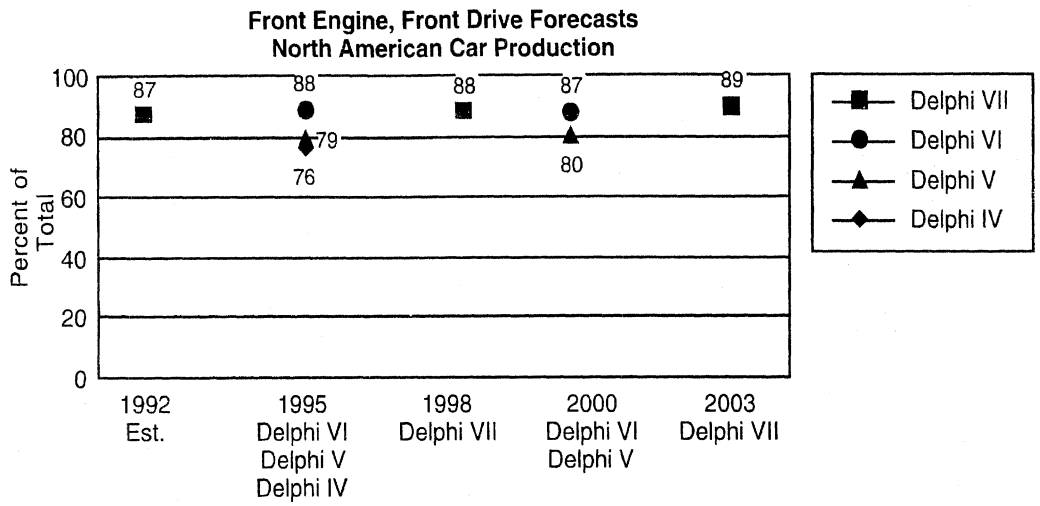
Comparison of forecast: MKT-40

Both surveys address four-wheel drive. Technology and Marketing panelists are generally in agreement.

Trend from previous Delphi surveys

Drivetrain Configurations	1995			1998	2000		2003
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Front Engine							
Front drive	76%	79%	88%	88%	80%	87%	89%
Rear drive	17	18	11	10	15	10	10
Mid-Engine							
Rear drive	2	0.5	n/a	n/a	0.5	n/a	n/a
Front Engine							
Four-wheel drive	5	3	1	1	5	3	1

The dominance of front engine, front drive is expected to continue in the next decade, as forecast in this and previous surveys. This dominance has been confirmed with escalating conviction in each of the last four surveys, as shown in the following graph.



The forecast for four-wheel drive continues to decline with each new survey.

Strategic considerations

The requirement for highly fuel efficient vehicles certainly favors the front engine, front drive configuration because of superior vehicle packaging. High performance vehicles or those designed for towing large loads will continue to use front engine, rear drive configurations, although progress is being made with front drive. The narrow interquartile range for these configurations indicates that there is a relatively high degree of agreement and certainty in this projection.

The interest in four-wheel drive passenger cars continues to decline. This apparently reflects the lack of value placed on this feature by the customer and perhaps the gain in popularity of four-wheel drive sport utility vehicles. The high cost cannot be justified in the eyes of most customers by the number of occasions that the feature is needed. Customers' comfort level with the traction characteristics of front-wheel drive may also be a factor in this shift away from four-wheel drive. Finally, the emergence of traction control is seen as a lower cost, albeit less effective, alternative to four-wheel drive.

TECH-91 What percentage of North American-produced passenger car transmissions will incorporate electronic control (excluding lock-up torque converter) in 1998 and 2003?

Transmissions incorporating electronic control	Median Response		Interquartile Range	
	1998	2003	1998	2003
	60%	90%	35/80%	75/100%

Selected edited comments

- This depends on factors controlling the pace of changeover (e.g., "doing" a new model).

Discussion

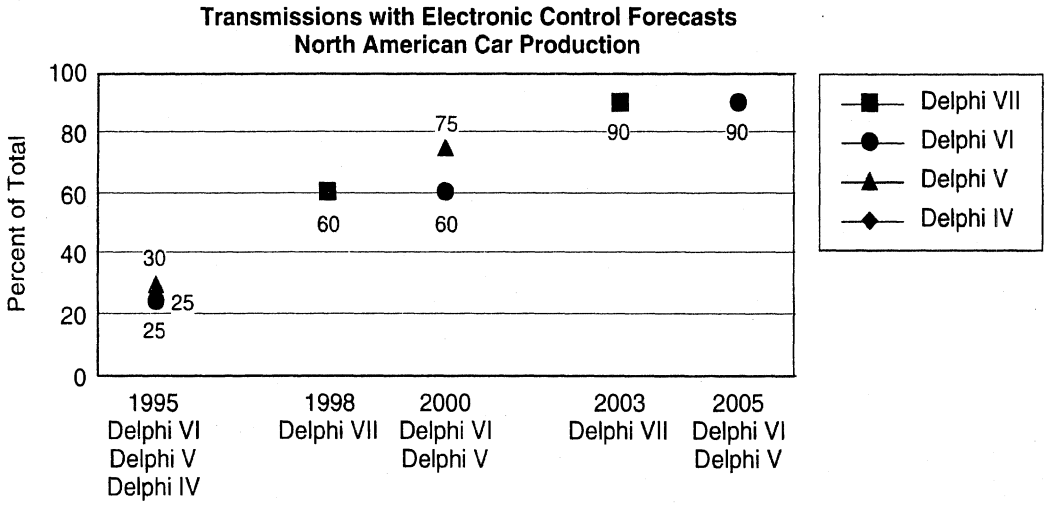
The trend toward electronic control of transmissions is driven by fuel economy, improved shift quality, the need to integrate the control of engines and transmissions into a synchronous system, and the reduction in the cost of electronics. Our panelist see this trend continuing for the next decade, such that application of this feature will approach 100 percent. The die is cast in this area. Essentially every automatic transmission program includes a switch to electronic control.

Manufacturer/supplier comparison

Manufacturers forecast greater application of transmissions incorporating electronic control for 1998, per the following table. The two panels are essentially in agreement for 2003.

Transmissions incorporating electronic control	1998		2003	
	Manufacturers	Suppliers	Manufacturers	Suppliers
	75%	50%	100%	90%

Trend from previous Delphi surveys



Results of the current survey generally follow the same trend line of previous surveys.

Strategic considerations

Electronic control of transmissions is an important feature providing enhanced customer satisfaction. Panelists project that this design will become a standard feature in the next decade. Component cost is an issue with the ramifications discussed in previous questions relative to vehicle affordability. The higher cost of electronic transmissions today may be reduced or overcome in the future with decreasing electronics costs and increased design and production experience.

TECH-92 What percentage of passenger cars will use electrorheological fluids in torque converters by MY 2003?

Passenger Cars	Median Response MY 2003	Interquartile Range MY 2003
Electrorheological fluids use in torque converters	2%	0/5%

Selected edited comments

- Control type applications could be first areas of use. There is a high voltage supply problem.
- Electrorheological fluids are getting better. The market could see a variety of niche products by 2003.
- It is hard to predict the required breakthrough in cost/temperature stability—without which ER torque converters will not happen.
- This is still a technical and cost problem.

Discussion

The use of electrorheological fluids in transmission torque converters is expected to be minimal in the next decade.

Manufacturer/supplier comparisons

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

Strategic considerations

Technical problems and cost continue to prohibit the use of electrorheological fluids in torque converters. Breakthroughs in these areas could change this picture, however. If the technology proves feasible, it will be intriguing to see what internal transmission components are altered and how their suppliers will be impacted.

TECH-93 What percentage of North American-produced passenger cars will incorporate a type of "T-drive" technology by the years 1998 and 2003?

Percentage T-drive by	Median Response		Interquartile Range	
	1998	2003	1998	2003
	0%	1%	0/1%	0/4%

Selected edited comment

- There is a major gear noise issue!

Discussion

No significant application of "T-drive" drivetrain is expected in the next decade.

Manufacturer/supplier comparison

Manufacturers forecast no application of T-drive, whereas suppliers forecast application rates of 1 percent and 2 percent for 1998 and 2003, respectively.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey, with a median response of 2 percent for 2000. Our current panelists are even less optimistic regarding the application of this design.

Strategic considerations

Ford exhibited a T-drive system at the 1991 North American International Auto Show in which the transmission input is taken off the midpoint of a transversely mounted engine. The resulting package is more compact than the conventional transverse engine front drive configuration. Our panelists do not project significant application of this design. The reason may be encompassed in the single selected comment as well as a perception there is little real benefit considering the substantial engineering and tooling costs involved.

The Chrysler LH car approach with a fore-aft engine may be a superior approach for the reasons stated in TECH-43.

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TECH-94 What percentage of total vehicle cost of North American-produced passenger cars will electronic componentry comprise in 1998 and 2003?

		Median Response		Interquartile Range	
Electronic Componentry as Percentage of Total Vehicle Cost	Est. 1991*	1998	2003	1998	2003
	10%	15%	20%	12/15%	15/20%

* **Source:** 1992 Delphi VI Forecast and Analysis.

Selected edited comments

- Increased electronic applications will be somewhat offset by lower unit cost.
- The amount will increase but cost will decrease, hence balance.
- There's a race between adding features and functions and reducing costs of established functions.

Discussion

As new electronic functions and features are added to the vehicle, the cost of each individual feature and function will continue to decrease. Panelists forecast an increase in the total percentage of electronic componentry. This would imply that features and functions will be added at a rate greater than that of decreasing cost. This appears to be particularly true in the rapidly emerging areas for electronics including the chassis, powertrain, safety, emission diagnostics and navigation systems. This continuing growth will prompt more and more attention by the electronics industry. A continuing challenge of the electronics revolution will be effective systems integration. It seems clear that the manufacturers will remain highly integrated in this area.

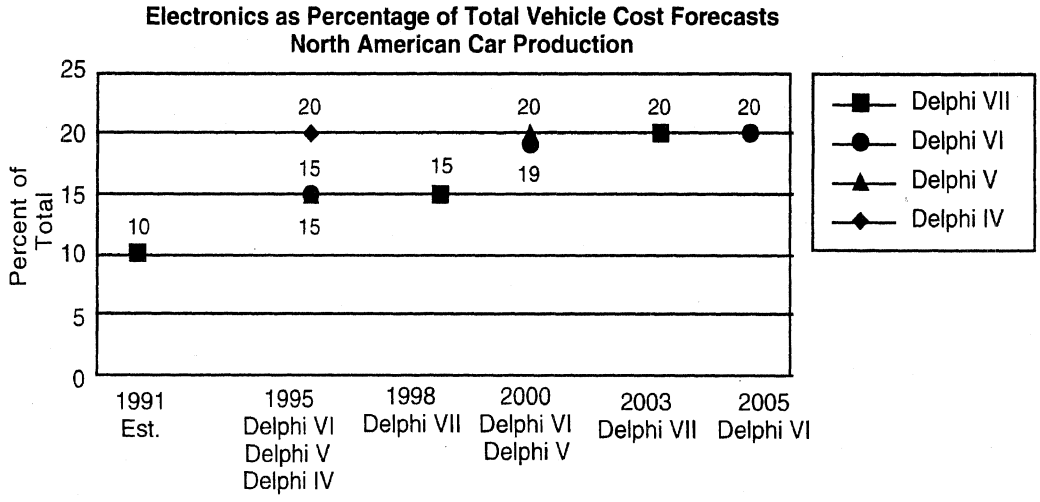
Current and expected legislation will require significant increases in the use of electronics. This is particularly true in the diagnostic requirements for emissions controls. The integration of electronic systems into the total vehicle will provide a significant challenge to engineers in the future.

Finally, the use of electronics is limited to a large extent by the ability of engineers to discover new techniques for the control of vehicle systems and the invention of new features for the customer. The future will certainly bring us uses for electronics that are not dreamed of today. The opportunities in electronics remain abundant.

Manufacturer/supplier comparison

Manufacturers and suppliers are in essential agreement.

Trend from previous Delphi surveys



The results of this survey are in general agreement with past surveys, particularly beyond 2000. A significantly higher forecast for 1995 was made in the 1987 Delphi IV survey, however, than was made in the three more recent surveys.

Strategic considerations

The expected increase in the total cost of vehicle electronics will probably add significant cost pressures to other systems. It is important to minimize the total vehicle cost increase to aid customer affordability. As stated in previous questions, we are at or have exceeded the cost threshold of many customers today in many segments of the market.

TECH-95 What percentage of North American-produced passenger cars will utilize at least one multiplexed (MPX) power subsystem by 1998 and 2003? Please estimate for current vehicles.

Passenger Car	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
Multiplexed Power Subsystem Utilization	1%	5%	10%	1/5%	2/10%	5/25%

Selected edited comment

- Signal multiplexing is practical and proven. Frequency and/or amplitude modulation provide excellent discrimination. Power multiplexing is inherently expensive, unreliable and dependent on transducers that are not conducive to solid state designs.

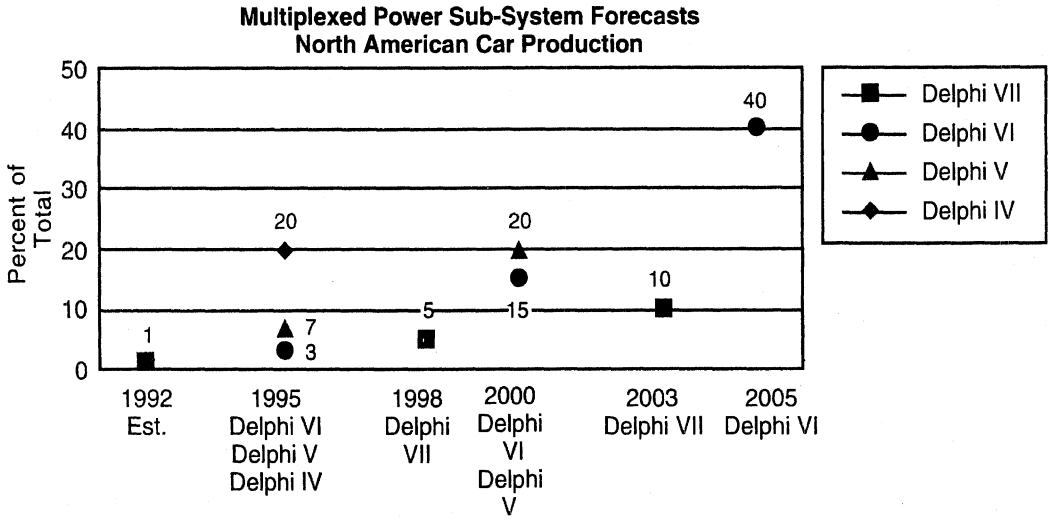
Discussion

Panelists forecast the increased application of multiplexed electrical power subsystems in the next decade.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys



Multiplexed power subsystems appear to be pushed further into the future with each new survey.

Strategic considerations

Multiplexing of power systems is a technology which holds promise for the future, but the timing of this application is in question. The wide interquartile range for 2003 indicates a high degree of uncertainty or variance in strategies on this matter. There are major incentives of cost, weight and space reduction, and potentially improved reliability and diagnostics with multiplexing. The development and validation of this system at a cost-effective level continues to be seen on the horizon, but a major application rate is in the distant future. Clearly this technology must be monitored closely since a breakthrough could alter expectations considerably and impact many parts of the vehicle and supplier community.

TECH-96 What percentage of multiplexed systems will utilize a fiber optic control bus technique rather than wire control bus by 1998 and 2003?

	Median Response		Interquartile Range	
	1998	2003	1998	2003
Multiplexed Systems Utilizing Fiber optics	2%	10%	0/10%	5/20%

Selected edited comments

- Fiber connectors are expensive and unreliable. To use fiber for control rather than direct delivery of light is neither quality nor cost effective. The concept of a central light source is neither fault tolerant nor fail-safe!
- There is growth seen for reliability/reduced electro-magnetic compatibility (EMC).

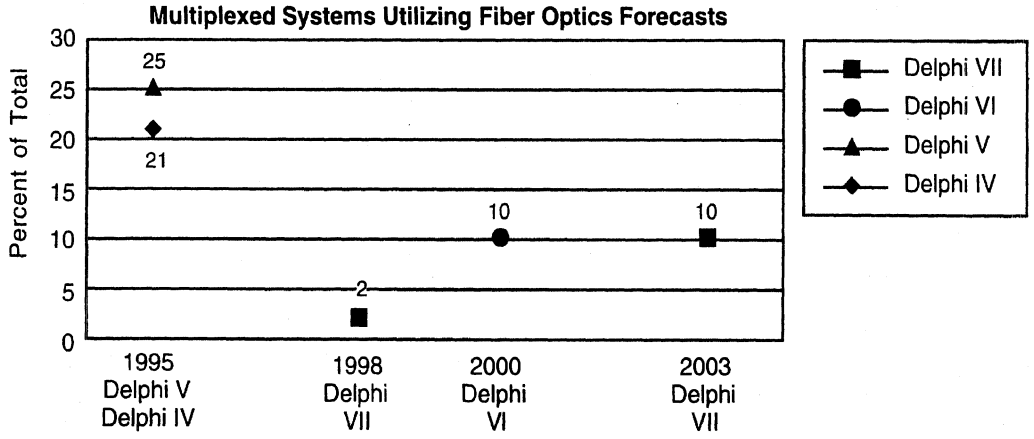
Discussion

Panelists forecast some application of multiplexed power subsystems utilizing a fiber optic control bus in the next decade, but significant barriers exist to broad application.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys



With each new Delphi, the use of fiber optics in multiplexed systems is pushed further into the future with lower near-term utilization.

Strategic considerations

The projected delay and reduced volume expectations for fiber optics are probably best summarized in the first selected comment. Cost and reliability must be superior to an electrically wired system before fiber optics can see any significant application. Our panelists see the beginning of this switch in the next decade, but reliable and cost effective systems must be developed and demonstrated. The issue of a central light source may be addressed through the use of multiple sources with a warning device when one is not functional. This will add cost, however, which must be factored into the comparison with conventional electrical wiring.

TECH-97 What percentage of North American-produced passenger cars will employ the following electronic/electrical features in 1998 and 2003?

Electronic/Electrical Features	Est. 1991*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Antitheft	9%	15%	25%	12/20%	15/30%
CD player	2	6	15	5/10	10/30
Cellular phones	0.6	5	10	2/10	6/25
Cruise control	72	75	80	75/80	80/90
Digital audio tape (DAT)	0	2	5	1/5	2/10
Drive-by-wire (electronic throttle control)	0	2	7	1/5	2/20
Electronic keyless entry	13	20	25	15/25	20/50
On-board diagnostic via expert systems (AI)	0	2	10	1/10	5/25
Voice activated/interactive controls	0	1	2	0/2	1/10

***Source:** *Ward's Automotive Yearbook*, 1992.

Other responses include:

Electronic Feature	1998	2003
Integrated belts	0.1%	0.5%
Phillips standard	4	40
Satellite mapping	2	5

Selected edited comments

- Antitheft includes "smart" ID of components–embedded chips.
- As the aircraft industry has discovered, electrical is not more reliable than mechanical in many applications. Electrical has difficulty delivering "muscle" and is dependent on a single power source that does not fail softly.
- Electronic keyless entry is tied to antitheft.
- Lack of cellular phone portability will limit market acceptance (monthly cost of car phone service).
- Some OBDII will be artificial intelligence (AI) since the emissions will be inferred.
- The adoption of many features will be accelerated as volume rises and cost and price come down the volume/learning curve.

Discussion

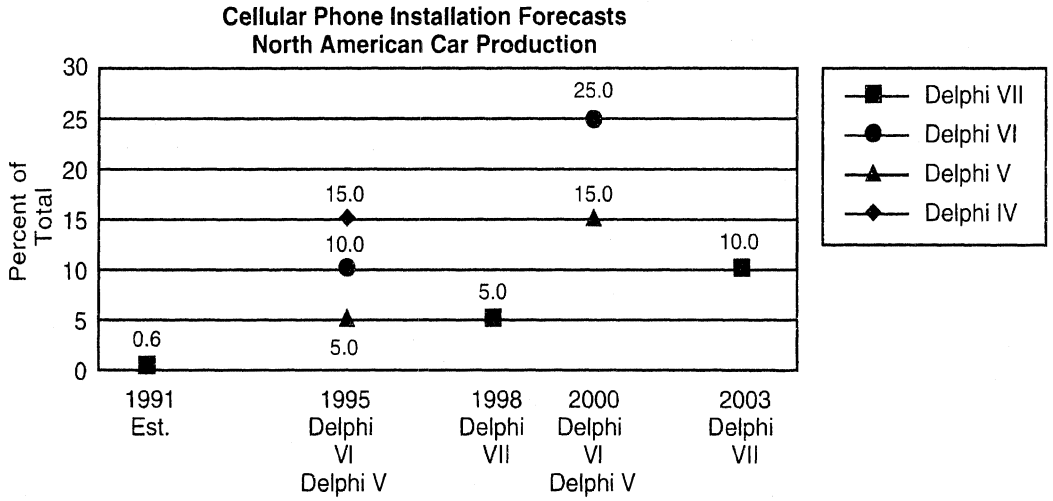
Panelists forecast significant growth in the use of many electronic features, and some application for features not currently used.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Electronic Features	1995			1998	2000		2003
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Cellular phones	15%	5%	10%	5%	15%	25%	10%
Cruise control	—	—	70	75	—	90	80
Drive-by-wire (electronic throttle control)	5	1	2	2	5	10	7
Electronic keyless entry	15	5	10	20	15	25	25
On-board diagnostic via expert systems-AI	—	—	5	2	—	15	10
Voice activated/interactive controls	10	1	1	1	2	2	2



Current panelists forecast lower installation rates of cellular phones than did previous panelists. This shift in direction may be a result of the lack of portability of vehicle installed phones and the general popularity of aftermarket systems.

Cruise control: Application rates are expected to continue to increase throughout the next decade, but current panelists do not see as strong an increase as the previous panelists. The 1992 Delphi VI panelists forecast 90 percent application by 2000, whereas current panelists forecast 80 percent by then.

Drive-by-wire: Current panelists are in general agreement with previous panelists.

Electronic keyless entry: Current panelists are in general agreement with previous panelists.

On-board diagnostics via expert systems (AI): Current panelists forecast lower application rates than those of the 1992 Delphi VI survey.

Voice activated/interactive controls: Current forecasts are in line with the previous two forecasts, but significantly below those of the 1987 Delphi IV survey.

Strategic considerations

The increase in the use of electronic features is, in some cases, modestly less than evident in previous forecasts. For example, cruise control, cellular phones and on-board diagnostics via expert systems all have less expected penetration for 2003 than was forecast from previous surveys. The reasons for this decrease may include development or cost reduction delays, a change in the customer acceptance rate of costly options, or a growing perception of a more acceptable option as may be the case with portable aftermarket cellular phones.

Vehicle cost increases as a result of emissions, safety and fuel economy standards will compete with consumer dollars for optional equipment or new technical features. The changing customer definition of value and increased basic vehicle cost will certainly have a profound impact on all nonregulatory driven features.

TECH-98 What percentage of passenger cars produced in North America will utilize the following system voltages by MY 2003?

Voltage level	Median Response MY 2003	Interquartile Range MY 2003
12V	90%	75/95%
24V	0	0/10
36V	0	0/0
48V	0	0/0
12/24V	0	0/5
12/36V	0	0/0
12/48V	0	0/3

Selected edited comments

- Higher voltage systems are inevitable, but I cannot guess how high.
- It will have to be a dual system, at first, to save cost.
- Major roadblocks will be the cost of tooling and the availability of increased voltage modules.

Discussion

In spite of considerable interest in higher voltage electrical systems in the vehicle, the current 12V system is expected to be used in almost all passenger cars through 2003. The need for a change in voltage is driven by the continuing increase in electrical loads as more and more electrical/electronic options, features and systems are added to the vehicle. High current levels with the current 12V system result in reduced efficiency of the electrical system. This may be an increasingly important factor as fuel economy requirements increase. Another driving factor is the increasing size of alternators to supply vehicle power requirements. These larger alternators are increasingly difficult to package, particularly with the pressure to reduce vehicle size and weight.

Manufacturer/supplier comparisons

There is some difference between responses from manufacturers and suppliers with regard to 24V and 12/48V systems. Responses for these system voltages are summarized below in the format lowest quartile/median/highest quartile.

Voltage level	Median Response MY 2003		Interquartile Range MY 2003	
	Manufacturers	Suppliers	Manufacturers	Suppliers
12V	90%	80	85/97	70/90
24V	0	10	0/5	0/15
12/48V	0	0	0/10	0/1

The median for 24V systems was zero percent for manufacturers and 10 percent for suppliers. On the other hand, 25 percent of the manufacturers forecast at least 10 percent penetration of 12/48V systems, versus only 1 percent for suppliers. There appears to be much uncertainty in this area, but there may also be a communication problem between manufacturers and suppliers on this issue.

Trend from previous Delphi surveys

In the 1992 Delphi VI survey, panelists were asked if they expected vehicle electrical-system voltages to be increased over the 12-volt level by 2000 and, if yes, what voltage was expected by 2000.

Forecast of Electrical System Voltage Increase by 2000		
	Yes	No
1992 Delphi VI	78%	22%
1989 Delphi V	58	42

1992 Delphi VI Results Voltage Level (percent of responses)		
24V: 25%	36V: 2%	48V: 10%
12/24V: 30%	12/36V: 3%	12/48V: 30%

Results from the current survey and the 1992 Delphi VI survey are in agreement with respect to the candidate system voltages being 12; 24; 12/24; or 12/48V. Application rates were not addressed in previous forecasts, but 78 percent of respondents in the 1992 Delphi VI survey expected some application of system voltages greater than 12V.

Strategic considerations

The change to any other voltage or combination of voltages from the current 12V systems will have a major impact on suppliers of electrical components for OEM and service parts. From the responses to this and past surveys, there is no consensus regarding future voltage levels—only that there probably will be a change at some time. The phase-in period to a new voltage level or levels will require considerable planning within the industry. It will also require considerable capital expenditures as components are redesigned and retooled.

It is in the best interest of all concerned that any change be made on a cooperative basis between manufacturers and suppliers to minimize the cost impact and to allow an orderly transition. An agreement between vehicle manufacturers regarding the new voltage levels will save considerable future tooling and service parts infrastructure costs. The best forum for the planning of this transition may be the Society of Automotive Engineers, where the issue is being actively considered.

TECH-99 **How many rotating and linear electric motors will standard and upscale North American-produced passenger cars have in 1998 and 2003? Include door locks, mirrors and trunk lid actuators. Please provide your estimate for current vehicles.**

Passenger Cars Having Rotating and Linear Electric Motors	Median Response			Interquartile Range		
	Current Est.	1998	2003	Current Est.	1998	2003
Standard <$25,000	9	12	15	5/15	10/18	12/25
Upscale >$25,000	16	20	24	12/32	15/40	20/45

No comments

Discussion

An increase of over 50 percent in the number of electric motors is anticipated in the next decade. This reflects the increasing customer demand for new features and conveniences, as well as the requirements to meet regulations in the areas of safety, emissions and fuel economy. As mentioned previously, the customer demand for increased electrical features runs counter to the need to improve fuel economy.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey. Results of the two surveys are in very close agreement.

Strategic considerations

This issue is closely tied to the previous question regarding the voltage level of future vehicles. The increase in electric motors is one of the driving factors in the need to increase system voltage. In fact, the future number of motors may be limited if the system voltage does not increase.

TECH-100 What percentage of North American-produced passenger cars will be equipped with these electric motor driven devices by 1998 and 2003?

Electric Motor Driven:	Median Response		Interquartile Range	
	1998	2003	1998	2003
A/C compressor	0%	5%	0/1%	2/5%
Air pump	3	5	1/5	5/20
Water pump	0	3	0/1	0/5
Power brakes	0	5	0/2	0/10
Power steering pump	1	5	0/5	2/10

Selected edited comments

- ABS already uses an electric motor-driven pump.
- As energy-efficient, lightweight components are developed for EVs, they will see increased use in IC vehicles. Batteries will handle load-leveling.
- Electric power is most desirable for low-duty cycle applications (due to energy conversion efficiency/loss), or where mandated by packaging constraints that preclude conventional mechanical hardware.
- Electric power will need to be carefully constrained/allocated.
- Inherent mechanical/conversion efficiency concerns will restrict usage of electrical motors for applications with high "on-cycles."
- This depends largely on electric vehicle sales.

Discussion

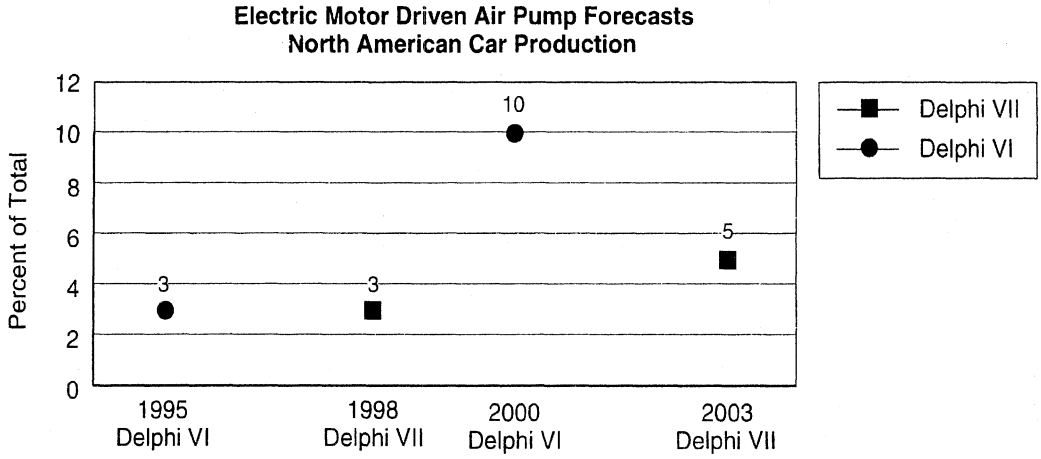
Electric motor-driven A/C compressors, air pumps and water pumps are expected to see 5 percent use or less by 2003.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey. Results for water pump and A/C compressor are in very close agreement with the current survey. The power steering pump question is new. Forecast usage of an electric motor for the air pump may be somewhat reduced in the current survey as shown in the following graph.



It should be noted that the interquartile range is large in most instances, indicating uncertainty or different strategies within the industry.

Strategic considerations

The electric motor-driven components addressed in this question require significant power. Minor penetration is forecast in the next decade. The limiting factor of alternator size will be significant to the long-term future application of these devices. Possible increases in system voltage could improve the outlook for use. Load management or prioritizing will be required in the vehicle to limit alternator output to a practical level.

Fuel economy may be improved by the use of electric motor-driven devices that have low duty cycles, as the parasitic load is very small when the device is not operating.

Finally, electric motor-driven devices may facilitate underhood packaging and consequently underhood temperature management.

TECH-101 What percentage of North American-produced passenger cars will utilize noise cancellation technologies by MYs 1998 and 2003?

Technologies	Median Response		Interquartile Range	
	1998	2003	1998	2003
Electronic Interior Noise Cancellation				
Digital signal processing (DSP) systems integrated into audio systems	1%	5%	0/2%	2/10%
None (not technically or economically viable)	98	95	95/99	90/98
Total	99%	100%		
Electronic exhaust noise cancellation				
"Electronic" muffler	1	5	0.1/2	1/10
None (not technically or economically viable)	99	98	98/100	90/99
Total	100%	103%		

Other responses (electronic interior noise cancellation) include:
Cabin systems–1998: 5 percent; 2003: 10 percent.

Climate control noise cancellation–1998: 3 percent; 2003: 5 percent.

Headrest–2003: 3 percent.

Selected edited comments

- The electronic muffler will be justified by reduced noise/back pressure if it proves reliable.

Discussion

Electronic interior noise cancellation and electronic mufflers are each expected to have a penetration of 5 percent by 2003.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey for 2000. In that survey, electronic noise cancellation was forecast to have a penetration of 10 percent by 2000 as compared to 5 percent for 2003 in the current survey. Likewise, the electronic muffler was forecast to have a penetration of 10 percent by 2000, as opposed to 5 percent by 2003 in the current survey.

Strategic considerations

The technology for electronic noise cancellation has been proven. Cost and complexity are the prohibiting factors. The forecast for the next decade is very limited application of this technology. Applications are likely initially in the high-priced end of the market. Performance image vehicles could also benefit from the potential reduction in exhaust back pressure possible with the use of an electronic muffler. This is another area where unexpected technological developments could sharply alter the forecast. Consequently developments should be closely monitored.

Other Issues

TECH-102 Considering the technical complexity of vehicles, please forecast the change in share of service activity for dealerships over the next 10 years (1994-2003). Please indicate your response where 1 = sharply increase and 5 = sharply decrease.

Dealership Service Activity	Mean Rating
Electrical/electronics	1.6
Non-CFC refrigerant conversion	1.8
Body shop	2.9
Mechanical	3.7

Other responses followed by its rating:
Airbag: 1; Non-warranty service: 4.

Selected edited comments

- Electrical/electronics should be separated into vehicle electrical/electronics and other/consumer electrical/electronics (cellular phone, audio, navigation systems, etc.). Vehicle electrical/electronics will bring more dealer business as diagnostic equipment becomes more specialized. Lower costs will take audio and cellular phone business to independent dealers.
- Legislation regulating CFC usage will determine whether dealers or others benefit.
- Reliability/quality will continue to increase. Total dealer shop activity on a per-vehicle basis may go down over the next 10 years.

Discussion

Panelists forecast increased service by dealerships in the areas of electrical/electronics and non-CFC refrigerant conversion over the next 10 years. They also forecast a decrease in mechanical systems service and little or no change in the body shop.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey. The format has been changed, however, such that the results are not directly comparable. The results from the 1992 Delphi VI survey are summarized below.

Automotive Repair Service	Percent of Automotive Service			
	Dealership		Aftermarket	
	1995	2000	1995	2000
Electrical/electronic	80%	80%	20%	20%
Mechanical	50	55	45	40
Total percent of auto service	55	60	40	40

Directionally, the results of the two surveys do not agree, as summarized below.

Dealership Service Activity Direction of Change in Next 8-10 Years		
Automotive Repair Service	1992 Delphi VI	1994 Delphi VII
Electrical/electronic	Unchanged	Increase
Mechanical	Increase	Decrease

Strategic considerations

As vehicle systems become more complex, it is likely dealerships will see increased service business. This is true in areas such as electronic systems where a high degree of technical expertise is required. Some electronic components such as radios, tape decks, CD players and cellular phones will continue to be sold and serviced in the aftermarket, however.

The continuing increase in vehicle reliability is forecast to have a negative impact on the service activity of both dealers and the aftermarket facilities. On the other hand, new requirements (such as the need to service air conditioning systems with non-CFC refrigerants and components) will likely increase overall service activity. New features and systems added in the future (such as increased airbag use and greater complexity of future emission control systems) will also tend to increase service requirements. Extended warranties may increase dealership service business.

Our panelists forecast a decrease in the service of mechanical systems by dealerships, and little or no change in the body shop.

An important factor in future service will be vehicle onboard diagnostics systems. As diagnostics are improved, service could be simplified for some systems and service/maintenance may be shifted more to need rather than schedule. This could have a profound effect on service parts and fluids.

TECH-103 **Please indicate skill areas and job functions where labor supply deficiencies currently exist and/or are likely to develop by 2003. Please enter a number from 1-5 where 1 = extremely severe and 5 = not at all severe.**

Occupation/Training	Job Function/Skill	Current/2003	Degree of Severity
Example: Mechanical Engineer	Product Design	Current	2
Example: Electrical Engineer	Circuit Design	2003	1

Summary of responses: (See Appendix for full listing)

Current Needs:

Occupation/Training	Number of Responses	Average Degree of Severity
Mechanical Engineer	16	1.7
Electrical Engineer	8	2.0
Mechanical/Electrical Eng.	5	1.4
Systems Engineer	5	1.6
Manufacturing Engineer	4	1.3
Software Engineer	4	1.0
Designer	3	1.7
Industrial Engineer	3	2.0
Service Technician	2	1.5
CAD/CAM/CAE	1	1.0
Electronics Technician	1	1.0
Engineer/Business	1	2.0
Ergonomics/Human Factors	1	2.0
Materials Manager	1	2.0
Process/Tool	1	1.0
Safety Engineer	1	2.0
Structural Engineer	1	2.0

Needs in the 1990's:

Occupation/Training	Number of Responses	Average Degree of Severity
Engineer - General	25	2.1
Chemical Engineer	6	3.0
Electrical Engineer	6	2.0
Mechanical Engineer	4	1.2
Materials Engineer	2	1.5
Metallurgical Engineer	2	3.0
Aerodynamics Engineer	1	1.0
Casting Engineer	1	1.0
Electronics Engineer	1	2.0
Environmental Engineer	1	1.0
Manufacturing Engineer	1	2.0

Needs beyond 2000:

Occupation/Training	Number of Responses	Average Degree of Severity
Mechanical Engineer	9	2.1
Electrical Engineer	5	1.8
Designer	3	1.0
Materials Engineer	3	1.3
Systems Engineer	3	1.7
Chemical Engineer	2	1.5
Electrical Technician	2	2.5
Manufacturing Engineer	2	2.0
Structural Engineer	2	1.5
CAD/CAE	1	3.0
Computer Science	1	2.0
Controls Engineer	1	2.0
Process Engineer	1	2.0

Selected edited comments

- CAD/CAM/CAE integration, better computers and networks will reduce manpower for all aspects of vehicle design. Good help will still (as always) be hard to get.
- Engineers will not be in short supply as conversion occurs and Third World nations (i.e., India) and poorer countries use intellectual talent at lower cost to improve their economies.
- Ford, Chrysler, GM, Siemens, Bosch, etc., just keep stealing these guys from each other. We need a net gain in this knowledge/experience pool.
- I do not see any persistent long-term shortages in any skills area service automotive field. Short-term shortages will tend to be self correcting.
- Skilled mechanical and electrical engineers capable of operating in the shop floor environment will be difficult to find.
- The transition to computer-based tools/methods/processes/systems will place a severe demand on migration and development on all areas of the business. Infrastructure will be challenged most in networks, data administration and product information management.
- There is a great need for much more investment in the knowledge and skills of engineers and technical leaders—especially the 32-64 year "consort." It needs to be customized to the individual and based on intelligent projections (not promises) of specific future needs and professional evaluation of offerings.
- There will be no shortage of supply if demand creates pay, conditions and treatment of engineers that encourages young students to enter field.
- We need more capability in model-based controls, model-based onboard diagnostics, linear and non-linear control theory and application to automotive products.

Discussion

Panelists have identified many diverse skill deficiencies for both the near and long term. Each organization must identify and deal with its own individual requirements, but the sum total as brought together here reflects on the areas of general shortfalls.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

Critical skills are important as indicated by the response to this question. There is, however, some opinion that some skill needs will not be a major problem (see comments). One factor that will certainly exacerbate human resource problems is the pace of technology and high degree of change in the industry. Furthermore, it will be crucial to manage the diversity of skills required. Highly competent and skilled people will be required across the span from advanced research to the shop floor. It will be vitally important for organizations to do an effective job of skilled human resource and knowledge planning. Leveraging resources from outside sources, such as national laboratories and universities, may be beneficial. Training and education will undoubtedly take on new meaning during the decade ahead. Successful companies will be those that effectively apply the concepts of a learning organization.

TECH-104 **As more components are engineered by suppliers (i.e., black box), the issue of vehicle integration becomes more complex. How significant a concern is this in the design/development/validation process? Please circle your response, where 1 = extremely significant and 5 = not at all significant.**

Mean Rating: 1.7 (very significant)

Selected edited comments

- Along with black box procurement comes responsibility for suppliers to understand interface and total vehicle interactions, which few are skilled at doing.
- Current U.S. practice does not have a systems engineering view.
- It should be integrated into the contract.
- Parts may work well on their own, but integration into vehicle environment causes issues/problems.
- Proper flowdown of design requirements to black box specifications will mitigate the severity of the problem.
- Suppliers will become team members, not just black box makers.
- Team building, partnerships and trust among specialty groups are musts.
- The ability of the supplier to engineer interactively with the OEM customer will be inhibited by lack of common CAD/CAE systems.
- There is a need to have excellent requirements that are rolled down to each component in a measurable way -- a tough task.

Discussion

In the view of our panelists, vehicle integration is a significant concern for supplier-engineered components.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

Continued downsizing by vehicle manufacturers will continue to result in more outsourcing of component design as well as manufacture. The key elements in making this process successful are suggested in the selected comments. Specifically, they include complete and accurate design requirements and specifications by the vehicle manufacturer, systems expertise at both the supplier and vehicle manufacturer, common design systems such as CAD/CAM, and a well developed team including the vehicle and component manufacturers.

Intense cost pressure on suppliers has the effect of reducing overhead such as systems engineering and interface personnel. Cost pressures at the vehicle manufacturer have a similar result. These functions must be viewed as requirements.

Design requirements and specifications supplied by the vehicle manufacturers are critical to an effective systems approach. Development of these requirements and specifications is painfully difficult and time-consuming, and is all too frequently inadequately done, or not done at all.

A team effort will be critical between manufacturers and suppliers throughout the entire process from design specifications to production.

The future success of vehicle manufacturers will depend to a large degree on their ability to manage this important aspect of the business.

TECH-105 **With increasing emphasis on vehicle aerodynamics, tighter underhood packaging, higher engine rpm and load, and other constraints, how much will underhood temperatures increase by 1998 and 2003?**

Increase in Underhood Temperature	Median Response		Interquartile Range	
	1998	2003	1998	2003
	10°F	10°F	5/10°F	5/20°F

Selected edited comments

- Better awareness and modeling techniques will help mitigate damage as will ever-improving materials.
- It cannot get higher while holding quality. It can be held with better air/heat management.
- It should remain the same. We will look for ways to cool underhood—temperatures are too high now!
- Underhood temperatures must be managed to current levels to ensure quality and high mileage durability.
- Underhood temperatures vary all over the place today—some are good, some are really hot. You can reduce underhood with better managed air flow at a plus cost or you can buy higher temperature components at a plus cost. This is a systems trade-off issue. You tell me the cost for higher temperature components and then I can predict temperature increases. Or, you tell me the temperature increase and I'll contact sources and predict the cost impact. There is no answer to the question as asked.
- Unless there is a change in underhood airflow and engine cooling technology, underhood temperatures can only increase due to the above and the more stringent emissions requirements.
- We are getting better at thermal management and will keep them from rising in spite of above trends.
- While heat loads will increase, better cooling techniques will be incorporated to compensate.

Discussion

Panelists forecast a 10°F increase in average underhood temperature for 1998 and 2003. The significant issues related to this matter are expanded upon in the Strategic Considerations section.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

This question was not asked in a directly comparable manner in a previous Delphi survey.

Strategic considerations

The selected comments summarize this issue quite well, and it is very important to read them carefully. This is a systems engineering issue that is receiving increased attention to optimize the cost trade-offs between component life, packaging, underhood cooling, aerodynamics and emission control. Manufacturers cannot ignore this issue if they are to avoid excessive cost or inadequate reliability. We must keep in mind that underhood temperatures vary considerably within the engine compartment (i.e., hot near the exhaust manifold and cooler near the grill opening). The general trend appears to be, however, to higher temperatures. Clearly this will exacerbate already serious material problems.

TECH-106 **What technology, materials, or manufacturing issues will present the most significant overall challenges or opportunities to the North American automotive industry in the coming decade?**

Summary of Responses: (See Appendix for individual responses)

Technology Challenges	Percent of panelists
Environment	36%
Fuel Economy	26
Integration of systems	8
Balancing requirements	3
Cost	2
New technology introduction	2
Other	17

Technology Opportunities	Percent of panelists
New component designs/features	11%
Integration	9
Computer capability	9
Emerging technologies	7
Materials	4
Communications	3
Electronics	2
Manufacturing	2
New products	2
Other	9

Materials Challenges	Percent of panelists
Balancing requirements	21%
Environment	15
Aluminum	8
Plastics	6
Composites	5
Manufacturing	2
Other	8

Materials Opportunities	Percent of panelists
Composites	7%
Requirements	7
Plastics	5
Aluminum	3
Manufacturing	1
Other	11

Manufacturing Challenges	Percent of panelists
Cost reduction	15%
Flexible/agile for low volume	13
New materials/processes	6
Quality	5
Cooperation/teamwork	4
Education/training	4
Lead time reduction	3
Other	6

Manufacturing Opportunities	Percent of panelists
Cost reduction	12%
Flexible/agile for low volume	12
Utilizing available technologies	7
Education/training	6
Quality	3
Cooperation/teamwork	2
Lead time reduction	1
Other	5

Strategic considerations

Please note the individual comments included in the Appendix. A single comment may have a clue to a new technology, material, design process or manufacturing process that is in the development stage somewhere in the industry.

Many issues such as cost reduction and composite materials are listed as both challenges and opportunities. Many of the opportunities available to the automotive industry have challenges associated with them which must be addressed to realize the potential of the opportunity. The organization that can best meet the challenges will be best positioned to reap the benefits. In addressing the many challenges facing the industry, it will be important that the organization leverage resources. This may include the use of resources at the supplier, national laboratories, contract organizations or universities. It is also important to consider that information and intelligence (software, training, etc.) may be as important as hardware.

The technology challenges noted most frequently related to the environment and a related area, fuel economy. Government regulation and a growing consumer awareness and interest are expected to drive these issues. The cost of not meeting these challenges may be an inability to sell vehicles in the worst case, or a cost and marketing disadvantage in the best case.

Numerous technology opportunities are noted. Each must be integrated into the organization and the product in order to optimize the product, customer satisfaction and corporate profits.

Most material challenges are also noted as opportunities. The greatest material challenges are expected to be balancing requirements and the environment.

Cost reduction is expected to be the greatest manufacturing challenge and opportunity. The concept of "re-engineering" as addressed in TECH-30 is expected to be applied to many areas of manufacturing, as noted in the comments.

The second highest manufacturing challenge and opportunity is expected to be flexible/agile manufacturing for low volume. Manufacturing low-volume vehicles at a profit will certainly provide both challenge and opportunity.

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Appendix

Appendix

TECH-103

Occupation/Training	Job Function/Skill	Current/2003	Degree of Severity
Example: Mechanical Engineer	**Product Design**	**Current**	**2**
Example: Electrical Engineer	**Circuit Design**	**2003**	**1**

Current Needs

■ CAD/CAM/CAE	Systems Support & Network Operation	Current	1
■ Designer - Engineering	Product Design	Current	2
■ Designer	Body	Current	1
■ Designer-Mech. Body	Product Design	Current	2
■ Electrical Engineer	All	Current	2
■ Electrical Engineer	Battery Design	Current	1
■ Electrical Engineer	Circuits Design	Current	3
■ Electrical Engineer	Power	Current	1
■ Electrical Engineer	Process Design and Implementation	Current	3
■ Electrical Engineer	Software	Current	2
■ Electrical Engineer	Vehicle Electrical Systems	Current	2
■ Electrical Engineer	Electronic Cont.	Current	2
■ Electronics Engineer	Circuit Design	Current	2
■ Electronics Technician	Car & Machine Troubleshoot	Current	1
■ Engineer/Business	Program Manager	Current	2
■ Ergonomics/Human Factors	Comfort/Conven./Safety	Current	2
■ Industrial Engineer	"Lean" Production	Current	1
■ Industrial Engineer	Process Development	Current	3
■ Industrial Engineer		Current	2
■ Manufacturing Engineer	Manufacturing Systems	Current	1
■ Manufacturing Engineer		Current	2
■ Manufacturing Engineer	Process Optimization	Current/2003	1
■ Manufacturing Engineer	Processing	Current	1
■ Materials Manager	Composite	Current	2
■ "Mechatronic" Engineer	Mechanical/Electrical	Current	1
■ Mech./Elec. Engineer	Analytical	Current	2
■ Mech./Elec. Engineer	Noise and Vibration	Current	1
■ Mech./Elec. Engineer	Powertrain/Calibration	Current	2
■ Mech./Elec. Engineer	With control systems training for new VCM hardware and software dev.	Current	1
■ Mechanical Engineer	All	Current	2
■ Mechanical Engineer	Analytical	Current	1
■ Mechanical Engineer	Art-to-Part	Current	1
■ Mechanical Engineer	Body-in-White	Current	3
■ Mechanical Engineer	Chassis Design	Current	2
■ Mechanical Engineer	Design	Current/2003	1
■ Mechanical Engineer	Process Design & Implementation	Current	2
■ Mechanical Engineer	Product Design	Current	2
■ Mechanical Engineer	Vehicle Development	Current	2
■ Mechanical Engineer	Vehicle Integration	Current	2
■ Mechanical Engineer	Calibration	Current	1
■ Mechanical Engineer	Emissions	Current	1
■ Mechanical Engineer	Product Design, Product Model Analysis and Process Dev.	Current	1
■ Mechanical Engineer	Process Design	Current	2
■ Mechanical Engineer	Powertrain	Current	2
■ Mechanical	Both		2
■ Mechanical/Elec. Engineer	Electronics to Mech. Systems	Current	1

Occupation/Training	Job Function/Skill	Current/2003	Degree of Severity
Example: Mechanical Engineer	**Product Design**	**Current**	**2**
Example: Electrical Engineer	**Circuit Design**	**2003**	**1**
■ Mechanical/Mfg. Engineer	Conceptual Design	Current/2003	1
■ Process/Tool	Lean Tooling	Current	1
■ Safety Engineer (Bio. Mech.)	Comfort/Conven./Safety	Current	2
■ Service Technician	Dealer Service	Current	2
■ Skilled Mechanics/Technician	Vehicle Diagnosis & Repair	Current/2003	1
■ S/W Engineer	Algorithim	Current	1
■ S/W Engineer	Programming	Current	1
■ Software Engineer	Control S/W	Current	1
■ Software Engineer	Vehicle Systems	Current	1
■ Structural Engineer	Finite Element Analysis	Current	2
■ Systems Engineer-Automot	Systems Engineering	Current/2003	1
■ Systems Engineer	Computer Systems	Current	2
■ Systems Engineer	Vehicle	Current	2
■ Systems Engineer	Mechanical/Electrical	Current	1
■ System Specialist	Product Creation	Current	2
Needs in the 1990s			
■ Casting Engineer	Program Chassis	1998	1
■ CFD Engineer	Design for Aerodynamics	1998	1
■ Chemical Engineer	Chemical Analysis Techniques	1990s	3
■ Chemical Engineer	Chemical Chromatography	1990s	3
■ Chemical Engineer	Development & Spec. of Organic Fluids	1990s	3
■ Chemical Engineer	Polymer Chemistry	1990s	3
■ Chemical Engineer	Spec. of Glazing Materials	1990s	3
■ Chemical/Material Engineer	Anti-Corrosion	1990s	3
■ Electrical Engineer	Batteries	1990s	1
■ Electrical Engineer	Circuit Design	1998	2
■ Electrical Engineer	Computers & Software Applications	1990s	3
■ Electrical Engineer	Electrical & Electronic Systems	1990s	1
■ Electrical Engineer	Electrical Integration	1998	3
■ Electrical Engineer	Motor Controllers & Electric Drive Motors	1990s	2
■ Electronics Engineer	Circuit Design	1998	2
■ Engineer	Adhesives, Coatings & Plating	1990s	3
■ Engineer	Body Design	1990s	2
■ Engineer	Body-in-White	1990s	2
■ Engineer	CATIA Knowledge	1990s	1
■ Engineer	Composite Manufacturing	1990s	3
■ Engineer	Crash/Dynamics	1990s	1
■ Engineer	Design & Development of EMC Modules	1990s	1
■ Engineer	Ergonomics/Factors Engineering	1990s	3
■ Engineer	Geometric Design	1990s	3
■ Engineer	Management & People Skills	1990s	3
■ Engineer	Manufacturing Processes	1990s	2
■ Engineer	Materials	1990s	2
■ Engineer	Noise, Vibration & Harshness (NVH)	1990s	1
■ Engineer	Packaging Skills	1990s	3
■ Engineer	Quality Systems Development	1990s	3
■ Engineer	Steering Control Systems	1990s	2
■ Engineer	Stereophotogrammetry	1990s	3

Occupation/Training	Job Function/Skill	Current/2003	Degree of Severity
Example: Mechanical Engineer	**Product Design**	**Current**	**2**
Example: Electrical Engineer	**Circuit Design**	**2003**	**1**
■ Engineer	Sterolithography	1990s	3
■ Engineer	Structural Analysis	1990s	2
■ Engineer	Surface & Systems Development	1990s	1
■ Engineer	Suspensions	1990s	2
■ Engineer	Test Design & Fabrication	1990s	2
■ Engineer	Thermodynamics	1990s	1
■ Engineer	Vehicle Perf. & Fuel Economy	1990s	1
■ Engineer	Wind Tunnel Operation	1990s	3
■ Environmentalist Engineer	Planning	1998	1
■ Manufacturing Engineer	Process Development	1998	2
■ Materials Engineer	Aluminum & Magnesium Casting	1990s	2
■ Materials Engineer	Composites	1998	1
■ Mechanical Engineer	Airbags/Safety Systems	1990s	1
■ Mechanical Engineer	Powertrain	1990s	1
■ Mechanical Engineer	Product Design	1998	2
■ Mechanical Engineer	Transmissions & Controls	1990s	1
■ Metallurgical Engineer	Metallography	1990s	3
■ Metallurgical Engineer	Metallurgy, Heat Treating & Lightweight Metals	1990s	3
Needs beyond 2000:			
■ CAD/CAE	Systems	2003	3
■ Chemical Engineer	Battery Design	2003	1
■ Chemical Engineer	Recycle Systems	2003	2
■ Computer Science	Programming	2003	2
■ Controls Engineer	Controls	2003	2
■ Designer-Mech. Body	Product Design	2003	1
■ Designers	Product Design	2003	1
■ Designer-Engineering	Product Design	2003	1
■ Electrical Engineer	Circuit Ass'y./Eqpt. Design	2003	2
■ Electrical Engineer	Electronics	2003	1
■ Electrical Engineer	Process Design & Implementation	2003	2
■ Electrical Engineer	Software	2003	2
■ Electrical Engineer	System Design	2003	2
■ Electrical Service Technician	Auto Repair	2003	2
■ Electronic Technician/Engr.	Repair/Maintenance of Production Equipment	2003	3
■ Manufacturing Engineer	Manufacturing Systems	2003	3
■ Material Engineer	Eff. Structures	2003	1
■ Materials Engineer	Materials R&D	2003	1
■ Materials Engineer	New Composites	2003	2
■ Mech. Engr./Elec. Engr.	Emission	2003	2
■ Mechanical Engineer	Analysis & Mechanical Design	2003	2
■ Mechanical Engineer	Art-to-Part	2003	1
■ Mechanical Engineer	CAD	2003	2
■ Mechanical Engineer	Impact Analysis	2003	2
■ Mechanical Engineer	Process Design & Implementation	2003	2
■ Mechanical Engineer	Product Concept	2003	1
■ Mechanical Engineer	Systems Development	2003	3
■ Mechanical Engineer	Process and Product	2003	3
■ Mechanical/Electrical Engineer	Electronics to Mech. Systems	2003	3
■ Mfg. Engineer (Process)	Plant Eng.	2000	1
■ Process Engineer	Micro Machines	2003	2

Occupation/Training	Job Function/Skill	Current/2003	Degree of Severity
Example: Mechanical Engineer	**Product Design**	**Current**	**2**
Example: Electrical Engineer	**Circuit Design**	**2003**	**1**
■ Structural Engineer	Eff. Structures	2003	1
■ System Engineer	Mfg. Process	2000	2
■ Systems Engineering Mgr	Product Program Dev. & Mgt.	2003	2
■ Vehicle Engineer	System Design	2003	1

Technology Challenges	Percent of panelists
Environment	**36%**
Emissions	15%
Recycling	7
Electric vehicle battery—low cost, high energy density	4
Electric vehicles	3
OBDII	3
Environmental aspects of design; Environmental concerns; Evaporative emissions; Recyclability of "fluff"	1% each
Fuel Economy	**26%**
Fuel economy	19%
Engine efficiency increase	2
Direct injection spark ignition	3
Engine friction reduction; Mass reduction without impacting customer	1% each
Integration of systems	**8%**
Electronic control of more functions and integration of their performance in a foolproof manner	3%
Application of electronic controls to mechanical systems; Electronic engine management–maintaining reliability; Integration of electrical/electronic requirements. Interactive components and functions; Integration of systems; Seamless and interactive CAD/CAE system between OEM and supplier base	1% each
Balancing requirements	**3%**
Meet more requirements at lower cost	1%
Meet system needs in short period with efficient designs	1
Optimization for reduced weight, low cost, higher efficiency, safety, etc.	1
Cost	**2%**
Controlling escalating computer budgets; Cost reduction	1% each
New technology introduction	**2%**
Applying known but not implemented technology to rapidly changing requirements; Proper rollout of electronic components	1% each
Other	**17%**
Reliability	3%
Vehicle repairability—easier, low cost	3
Aluminum and composite—low cost, high rate manufacturing and assembly; CAD systems—eliminate current incompatibilities; Electronic modeling vs. prototyping; Electronics efficiency; Improved performance; Lead time reduction in design of new vehicles; Life cycle vehicles that are regarded and managed in ways comparable to aircraft—with design life; Management—lack of knowledge and technology; Reliability qualification of materials without years of testing; Synthesis vs. analysis in design (deterministic); U.S. auto company joint efforts	1% each

Technology Opportunities	Percent of panelists
New component designs/features	**11%**
High tech sensors and control technologies—improved component performance without major redesign of hardware	3%
Batteries; Camless engine design; Electric motors/controls; Electrification of power steering and air conditioning; Engine valvetrain; Low cost EV batteries and controllers; Powertrain technology--high efficiency/high specific output; Transmission design	1% each
Computer capability	**9%**
Ability to do more predictive math simulations; Computer processing—faster, more simulation; Modeling to truly design "on the tube"	3% each
Integration	**9%**
Electronics integration	4%
Integration of vehicle subsystems for much improved performance at low cost	3
Designing complete systems vs. integrating components into systems; Synchronous system engineering	1% each
Emerging technologies	**7%**
Two-stroke engine; Advanced powertrain technologies; Fiber optics; Fluids (hydro and pneumatic amplifiers/switching devices); Lean burn NOx catalyst; Safety through active and passive technology applications; Smart accessories	1% each
Materials	**4%**
Alternate fuels; High temperature engine materials; Higher engine efficiencies through alternative fuels; Materials—composites	1% each
Communications	**3%**
Electronic knowledge capture and transmission; Information technologies to organize and control global experience and expertise; Using technology from government labs	1% each
Manufacturing	**2%**
Ability to have more flexible manufacturing; Taking technology to the factory floor	1% each
Electronics	**2%**
Electronic engine controls—smarter; Electronic logic and control deck; Electronics	1% each
New products	**2%**
Navigation systems; On-board maps	1% each
Other	**9%**
IVHS	3%
Develop technology to customers' desires, not engineers' desires; Ecology; Functionality; Improve CNG storage; Safety; Security; Time enhancement	1% each

Materials Challenges	Percent of panelists
Balancing requirements	**21%**
Lightweight	5%
Lightweight/low cost	3
Anti-corrosive but biodegradable or recycling; Battery—low cost/light weight/fast charge/long life; Cost; Durable, strong, light, low energy; Electronics environment (high temp); High strength/high temp; High strength/high weight; High strength/low weight; High temperature/lightweight; Higher temperature; Less cost/more durable; Lightweight/environmentally friendly; Strength/performance	1% each
Environment	**15%**
Recyclability--plastics	3%
Recycling	3
Bio-friendly lubricants; CFC free A/C interchangeable; Green materials that perform and are recycled; Minimize waste and maximize recycling; Non-toxic; Recyclability—glues; Recycle tires; Recycling composites; Toxic elimination	1% each
Aluminum	**8%**
Aluminum for body panels	3%
Aluminum—increased use	3
Aluminum—cost efficient bodies; Aluminum processing and joining	1% each
Plastics	**6%**
Plastic body—low cost (RTM, CCM, SMC, etc.)	2%
ER fluid availability; Plastic parts to tighten tolerances; Plastics; Plastic increase—thermoplastic manifolds	1% each
Composites	**5%**
Composites—lower cost	3%
Composites—increased use; Fast cycling molding and joining of composites	1% each
Manufacturing	**2%**
Aluminum/magnesium/plastic body fabrication and assembly process; Processing	1% each
Other	**8%**
Fuel systems for various fuels and mixtures; Infrastructure for new materials; Large increase in number of cycles to failure data; Materials that react automatically to inputs (windshields sense need for wiping and change light entry); Nonferrous materials—continued increase; Piston materials that allow elimination of upper crevice volumes and 25% of engine-out emissions; Rustproof—20-year body and exhaust system; Synthetic fuels	1% each

Materials Opportunities	Percent of panelists
Composites	**7%**
Composites	4%
Composites that adhere well and that are leakproof; Lightweight metal matrix composites; New composites and new processing techniques could significantly reduce vehicle mass	1% each
Requirements	**7%**
Better sound isolation/absorption of structural components; Increase use of aluminum/magnesium/plastic to reduce mass; Lightweight, strong material; Lightweight materials for body panels; Lightweight/increased strength; Lightweight/low cost materials	1% each
Plastics	**5%**
Plastic composites	2%
HS plastics; Plastic engine components; Plastic structural functions	1% each
Aluminum	**3%**
Aluminum	2%
Aluminum manufacturing assembly and repairability	1
Manufacturing	**1%**
Improved production processes	1%
Other	**11%**
Ceramics	2%
Electric car batteries; Foams; Magnesium; Non-CFC refrigerants; Replace nobel metals in catalytic converters with new catalyst including substrate; "Smart" materials to fill niches with good function at attractive prices; Synthetic fluids—especially for automatic transmission fluid; Theft deterrent materials; Water-based paints	1% each

Manufacturing Challenges	Percent of panelists
Cost reduction	**15%**
Lean manufacturing/production	5%
Cost reduction/efficiencies improvements	4
Assembly worker optimization (value-added vs. robot); Investment costs; Life cycle costing and efficiency; Low capital strategies and flexible/agile planning; Low energy requirements for machinery—develop; More rapid synchronous system employment; Reduce cost through better quality and employee empowerment	1% each
Flexible/agile for low volume	**13%**
Flexibility and agile manufacturing for niche volumes	6%
Flexibility	2
Agile with reduction variation; Flexibility at low investment; Handling lower volumes cost effectively; Low-cost, low-volume production; More smaller build models	1% each
New materials/processors	**6%**
Aluminum body fabrication and assembly; Develop cost-effective schemes to fabricate new materials and complex electronic boards with high quality; Greater application of aluminum/magnesium/plastic to challenge body fabrication and assembly process to deliver quality and low cost at high line rates; Improved high integrity casting processes for structural aluminum/magnesium chassis and body structure (i.e., IP beam) parts; Magnesium—safety; Maintaining high quality with new processes	1% each
Quality	**5%**
Manufacturing to tighter tolerances—reduced variations	3%
Capabilities forecasting to product design; Quality	1% each
Cooperation/teamwork	**4%**
Configuring a cooperative, integrated supply network; Language/education barrier between factory workers and management; Partnering with suppliers	1% each
Education/training	**4%**
Education of blue collar workforce; Shortage of skilled technicians for sophisticated equipment; Trained and skilled workforce that is motivated; Upgrading skill levels (engineering and production workers)	1% each
Lead time reduction	**3%**
Reduced leadtime	2%
Fast turnaround of designs with zero defects	1
Other	
Applying available technology—develop a plan; Inability to give up old, highly automated, inflexible plants and equipment; Integrated conductors and flat wire harnesses; Paint spray; Regulatory-emissions, EPA; Standardization inside with variety outside	1% each

Manufacturing Opportunities	Percent of panelists
Cost reduction	**12%**
Implement lean manufacturing systems	4%
Improved throughput from given asset base	4
Improved margins working in clusters with similar units on complex systems; Investment efficiency; Lower investment techniques; Reduced tooling costs	1% each
Flexible/agile for low volume	**12%**
Agile manufacturing development	3%
Downsized manufacturing units with focus and expertise; Flexibility; Flexible cells; Flexible manufacturing; Flexible manufacturing cells that check themselves for output and quality; Increased product range/flexibility; Industry collaboration required to achieve agile manufacturing excellence; Low volume manufacturing; True flexible manufacturing to allow profitable short runs	1% each
Utilizing available technologies	**7%**
Sensors for motion control	3%
CAD/CAM/CAE; Laser welding; Robotics; Taking advantage of available technology	1% each
Education/training	**6%**
Use of continual education of all workers so they are more valuable and productive	6%
Quality	**3%**
Adaptive control to ensure accuracy and precision; Increase quality; Variability reduction—continuous improvement	1% each
Cooperation/teamwork	**2%**
Capturing ideas of manufacturing workers; Concurrent engineering	1% each
Lead time reduction	**1%**
Lead times reduced	1%
Other	**5%**
Greater manufacturing R&D in advance of facility/equipment design; Improved manufacturing engineering technology; Paint systems—simple, clean, durable; Time-based manufacturing; Video imaging acceleration control	1% each

DEFINITION OF TERMS

Foreign Nameplates. Refers to all non-U.S.-headquartered vehicle manufacturers or dealership networks regardless of production location (i.e., Honda's U.S. production should be combined with their import vehicles).

Light truck. Includes sport utilities, vans and pick-up vehicles.

M.Y. Model Year. When a year(s) is referenced in a given question, it always refers to model year(s) unless otherwise specified.

Traditional Domestic or Big Three. Refers to all U.S.-headquartered (parent company) manufacturers or dealership networks regardless of production location (i.e., forecast for General Motors should include NUMMI-produced Prisms and imported Metros).

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