THE UNIVERSITY OF MICHIGAN

Forecast and Analysis of the U.S. Automotive Industry Through the Year 2000

- *MARKETING*
- *TECHNOLOGY*
- *MATERIALS*

VOLUME 2: TECHNOLOGY

DELPHI V FORECAST AND ANALYSIS OF THE U.S. AUTOMOTIVE INDUSTRY THROUGH THE YEAR 2000

TECHNOLOGY

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FOREWORD

INTRODUCTION

Delphi V is a detailed analysis of forecasts by three separate panels of automotive industry executives, directors, managers, and engineers who are expert in the areas of automotive technology, materials, and marketing. These individuals are selected because they occupy positions of responsibility within the automotive industry and have strategic insight on important industry trends. In many cases they are in a position to influence these trends. This report, published in three volumes, is the fifth in this series of in-depth studies of long-range automotive trends that began with Delphi I in 1979 and continued with Delphi II in 1981, Delphi III in 1984, and Delphi IV in 1987.

The Office for the Study of Automotive Transportation performs the data collection and analysis, presentation, and interpretation of the results. Since the forecasts we present are those of the panelists, Delphi V is, essentially a consensus industry forecast of itself. These forecasts are not "crystal ball" predictions, but rather well-informed estimates, predictions, and opinions. Such forecasts provide an important basis for business decisions and provide valuable strategic planning information for those involved in all areas of the North American automotive industry, including manufacturers; service, component, and material suppliers; government; labor; public utilities; and financial institutions. We believe these to be the most authoritative and dependable North American automotive trends available.

A key point to keep in mind with regard to the Delphi forecast is that it presents a vision of the future which is, in a sense, an important basis for industry decision-making. It is obviously not a precise statement of the future but rather what the industry *thinks* the future might be.

THE DELPHI METHOD: GENERAL BACKGROUND

This study is based on the Delphi forecasting process. With this method various groups of 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, iterative method of forecasting based on independent inputs regarding future events from these experts.

The Delphi method is dependent upon the judgment of knowledgeable experts. This is a particular strength of this method 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 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 objectives are to present the direction of technological, materials, and marketing developments within the industry and analyze potential strategic importance.

PROCESS

The Delphi method utilizes repeated rounds of questioning (accompanied by feedback of earlier-round responses of peers) to take advantage of group input while avoiding biasing effects often typical of 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 (cf. 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 the panelist to freely express his or her opinion. 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. This 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 of The University of Michigan faculty and staff and representatives of the automotive industry. Lists of prospective expert panelists were assembled: one each for Technology, Marketing, and Materials. Panel members were selected on the basis of the position they occupy within the automotive industry dealing with the topic being surveyed and are acknowledged to be 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 panel members are not made known to each other. Upon publication of the final Delphi report, all questionnaires and lists of panelists are destroyed.

The characteristics of the 330-member panels are as follows: 17% of the Technology Panel were composed of CEOs, presidents, or vice-presidents; 26% were directors; 36% managers or supervisors; 12% were engineers (chief, assistant chief, and staff); and 10% of the panel were made up of academic specialists and consulting technical engineering specialists. The Marketing Panel was composed of 22% CEOs, presidents or vice-presidents; 14% directors; 34% managers; 18% engineering specialists; and 16% academic and consulting marketing specialists. Among Materials panelists, 12% were CEOs, president and vice-presidents; 21% were directors; 36% managers and supervisors; 8% engineering specialists; and 23% academic and consulting materials specialists. Approximately 57% of the Delphi V panelists were employed by vehicle manufacturers, 32% by components and parts suppliers, and 11% were specialists, consultants, and academics.

PRESENTATION OF DELPHI FORECASTS AND ANALYSIS

When a question calls for a response in the form of a number, the group response is reported in terms of 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. The median value is the middle response, and 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% and the IQR 35–45%. This means that one-quarter of the respondents answered 35% or less, another one-quarter chose 45% or more, and the middle-half of all responses ranged between 35% and 45%, with 40% representing a measure of central tendency. That narrow interquartile range would indicate a fairly close consensus among the respondents.

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

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

Note that the median results are typically expressed as round numbers (5, 10, 50), rather than more specific-appearing numbers (e.g., 12.7, 45.3) which might develop if averages were used.

Discussion. Narrative discussions are presented, where necessary, 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 arrive at their forecasts.

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 shown in the report following the forecast tables. Redundant or derogatory comments are excluded. These replies may be important indicators that are not apparent in the numerical data. An individual panelist may be aware of something unique that planners should carefully consider. However, readers should be careful not to over-emphasize a particular comment. It is possible for a well-stated contrary opinion to mislead the reader into ignoring an important majority opinion that is represented by numerical data.

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

For obvious competitive reasons, the automotive vehicle 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 or perspective of the forecast, our analyses include a comparison of the forecasts from manufacturer and supplier panelists in an attempt to illustrate where significant agreements or differences exist between the opinions of the two groups.

Comparison of Panels. The three groups of Delphi panelists (Technology, Marketing, and Materials) are asked questions that specifically focus on their respective area of expertise. However, a few questions are considered common to two or more panels. The fuel-price question (see MKT–6) is considered so basic that it was submitted to all three panels.

At times, the panels will give differing responses to the same question. 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 interests 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 that collects and presents the opinions and attitudes of a group of experts at that particular point in time. Some questions, in various forms, were asked in previous Delphis. This has resulted in the accumulation of trend data in the Delphi forecasts since 1979. 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 is a reflection of the consensus of expert opinion at that time. These opinions and forecasts are predicated on the best information available at that time. Market, economic, and political factors change. An analysis of trend data can reveal either stability or volatility in a particular market factor, material, or technology. 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 relative Delphi V forecasts, other research and studies, and OSAT's extensive interaction with the automotive industry, inferences and interpretations are made as to the core issues in questions and their impact on the industry. By no means are they expected to be exhaustive statements of critical issues but rather points the reader should consider.

TECHNOLOGY CONTENTS

EXECUTIVE SUMMARY

The Delphi V Forecast and Analysis of the U.S. Automotive Industry Through the Year 2000 is the fifth in a series of biennial, multi-volume forecasts issued by the Office for the Study of Automotive Transportation (OSAT) of the University of Michigan Transportation Research Institute. These Delphi forecasts, initiated in 1979, present a consensus vision of the future through the eyes of key industry technical and marketing leaders.

The *Delphi V: Technology Volume* identifies, defines, and provides strategic analyses of new developments and emerging trends in automotive-related technologies. In addition, Delphi V provides forecasts and analyses of market-related issues such as quality, environmental, and legislative concerns, product/market penetration and segmentation, sourcing considerations, and supplier/aftermarket strategies—factors that will influence future technology and material selection decisions. The wide range of issues explored in Delphi V provides a useful leading indicator of major automotive technical trends through the next decade. The report divides these issues into major sections covering (1) *General Vehicle* issues, including regulatory and fuel concerns; (2) *Powertrain / Drivetrain*, including engine and transmission types; (4) and the role of *Electrical / Electronic* systems and components in the vehicle.

The Delphi V panelists' opinions and forecasts of automotive technology and related issues are at once cautious and optimistic. Clearly the winds of change are still blowing, but the rate of change forecast for the 1990s is, in many respects, more modest than that envisioned by panelists in 1987's Delphi IV. As the industry sharpens its focus on true and total customer satisfaction, there appears to be less enthusiasm for technology for technology's sake and more emphasis on value delivered. Heightened expectations for a variety of automotive regulations are certainly spurring some forms of technological change, but they are simultaneously moderating others. Nevertheless, new and developing automotive technologies will achieve a level of sophistication and application that ensures the production of a passenger vehicle that could have only been a dream just ten short years ago.

The automotive industry will face not only unprecedented challenge, but also significant opportunity in the coming decade. Many traditional quality and value factors will become less important as product differentiators, because most of the world's manufacturers will reach parity with one another on these traditional dimensions. They will become requirements for remaining in the competition, rather than keys to success. Technology will become an increasingly important differentiator, but only if it meets customer expectations of value at a reasonable price.

I. GENERAL VEHICLE ISSUES

Despite recent fuel price volatility, panelists forecast a generally stable energy future with only modest price increases through 2000. However, many of these experts believe that a significant energy shock is likely. The forecast calls for the appearance of methanol-based alternate fuels, and about 10% of North-American-produced vehicles to have flexible fuel capability by 2000. These results are in reasonable accord with recent pronouncements by the federal government. Delphi respondents expect fuel economy to improve, with gains in powertrain efficiency leading the way. On the other hand, they do not view further downsizing as a significant source of future improvement.

Panelists see high quality and low cost as absolutely key factors in future success, but they expect new technology, styling, market responsiveness (including lead-time reduction), and total customer sales and service satisfaction to be the critical market differentiators.

These experts anticipate a more aggressive regulatory climate across a range of fronts, from exhaust emissions to safety. Panelists suggest a wide variety of technologies to help meet these tougher requirements. Attitudes about future regulation seem to be more generally positive than has been the case in past Delphi studies.

The product development process is undergoing significant change because of competitive pressures. Panelists forecast significant lead-time reduction for North American manufacturers, both in reskinning existing vehicles and redesigning platform vehicles. nevertheless, they expect Japanese manufacturers to maintain their leadership position, although by a reduced margin.

These respondents expect the next decade to witness the emergence of true vehicle life-cycle (cradle-to-grave) management as an important consideration. Satisfying the customer and concerns about recycling are two factors spurring this development. Panelists expect the industry response to include better diagnostic capabilities, improved system reliability and serviceability, significantly enhanced warranties, and improved training. Changes in the service industry will accelerate, as emphasis on electronic module service and enhanced diagnostic capabilities increase. Developing issues regarding solid-waste disposal and recycling both result in panelists' strong support for the development of recyclable/biodegradable materials, OEM reclamation programs, and the inclusion of recycling as a vehicle design consideration. Finally, panelists believe capital investment and R&D expenditures should be expanded dramatically for both manufacturers and suppliers.

II. BODY/CHASSIS

Quality, foreign competition, market forces, styling, and durability are the factors panelists expect to have the most significant influence on vehicle design. It is noteworthy that labor cost has tumbled dramatically as a consideration compared to earlier Delphi surveys.

Panelists forecast a modest shift to international sourcing of engineering by the domestic manufacturers, even as the Japanese manufacturers source more engineering in North America. The forecast suggests that component sourcing will follow the same general patterns as the sourcing of engineering. However, there will be considerable moderation in the degree of offshore sourcing by the domestic manufacturers compared to expectations in prior Delphi surveys.

Panelists forecast that integral body/frame designs will dominate future body configurations, with just a small fraction allocated to separate body/frame and space-frame concepts. They expect steel to remain the dominant body/frame material; in fact, the significant shift to plastic exterior panels forecast in Delphi IV is not evident in the present Delphi V. The forecast suggests that future suspensions will begin incorporating more exotic features, including electronically controlled active and passive designs, non-metallic springs, and active four-wheel steering. However, most of these features will only achieve low market penetration levels. There is a dramatic reduction in the forecast use of electrical/ electronic power steering compared to Delphi IV. Panelists foresee accelerated use of rear independent suspension and increased use of twin A-arm designs in front suspensions. However, the MacPherson strut will continue its dominance. Anti-lock brakes (ABS) will dramatically expand their role, in the view of our panelists. In fact, many believe ABS will become a standard feature by the end of the next decade.

Delphi V respondents expect to see changes in tire and wheel technology as well, with growing use of mini-spares and, for a small fraction of future light-duty vehicles, elimination of the spare tire. This will be possible due to developments in puncture-resistant, self-sealing, or run-flat tire designs. Panelists expect to see styled wheels, made from aluminum, steel, and composites, in use for a growing portion of future passenger car.

Panelists forecast that vehicle interiors will incorporate significant increases in airbags and "friendly" designs to minimize injury to unrestrained passengers. A strong emphasis on function is evident, with anticipated increases in the use of ergonomically designed seats, features, and controls. The use of heads-up displays will accelerate, although our panelists have very mixed views on the value of this technology.

These experts forecast further reduction in the weight of North-American-produced passenger cars, although the weight reduction is far below the levels expected in earlier Delphis. The expected weight of the average car in the year 2000 is nearly 3,000 pounds. Panelists still expect significant growth in the use of plastics and aluminum, but without the major reduction in steel use reported in earlier forecasts. They also forecast growing importance for new materials in future vehicles, such as electro-rheological fluids, with applications ranging from engine mounts to shock absorbers.

III. POWERTRAIN/DRIVETRAIN

The forecast calls for major powertrain changes in the years ahead, and our panelists expect fundamental redesign of a significant fraction of present engines. Engines will be more precisely manufactured, incorporating a variety of advanced features, such as three- and four-valve cylinder heads, variable-valve timing, and single- or dual-overhead camshafts. However, the voice of the customer will dictate the actual degree of "up-teching" that will occur in future engines. Respondents expect multi-point electronic fuel injection to be the preferred fuel management system, followed by single-point injection, while carburetors will essentially disappear. Future ignition systems are moving in the direction of distributorless designs, while panelists expect that features such as individual cylinder and knock control and closed-loop timing will be incorporated in a large fraction of future engines.

The Delphi panelists expect engines and transmissions to use fully integrated electronic control to help meet more rigorous regulatory standards that call for both lower emission levels and greater durability. They see turbochargers and superchargers playing a limited but important role in future vehicles.

Consistent with their expectations of future vehicle downsizing, panelists forecast that the average number of engine cylinders and piston displacement will both be similar to current engines. Four- and six-cylinder designs will dominate, but the V-8 is forecast to play a significant role as well.

Delphi V forecasts major change in engine materials, but the changes are not as extensive as those forecast in Delphi IV. Panelists expect cylinder heads to be largely aluminum by the year 2000, but cylinder blocks are not expected to follow suit, although there will be some increased aluminum use here as well. Plastics, ceramics, and metal matrix composites will all be important future engine materials in a variety of special applications. Modest fractions of future engines will rely on plastic intake manifolds, valve covers, and oil pans; ceramic valve-train components and exhaust port liners; and metal-matrix-composite pistons and connecting rods.

The future for alternative powerplants is uncertain. Our experts foresee little likelihood that alternatives, such as the diesel, the stratified charge, the gas turbine, or the Wankel will exceed very small volumes in light-duty vehicles. While the spark-ignited, two-cycle engine has provoked considerable interest, panelists expect it to have little impact during the next decade. However, its progress should be monitored closely because of the magnitude of its potential impact on future vehicle design.

The forecast suggests some change in the drivetrain. However, panelists expect far lower application levels for such revolutionary technologies as the continuously variable transmission (CVT) than had been expected in previous Delphi studies. The front-engine, front-drive configuration will hold steady at about 80% of future passenger cars, with a continuing solid role for front-engine, rear-drive configurations. Four-wheel drive will have a role in future passenger cars, but it will be minor.

The forecast anticipates that automatic transmissions will be used in 87% of passenger cars during the 1990s, including a very modest percentage of CVTs and five-speed designs. Manual transmissions will generally feature 4- and 5-speeds, although a limited number of 6-speed designs are expected by the year 2000. Perhaps the major transmission development is the expected aggressive move to electronic control of automatic transmissions during the next decade.

IV. ELECTRICAL/ELECTRONIC SYSTEMS

This Delphi study see a continued expansion of the role of electronics in future vehicles, although expectations are somewhat lower than those of Delphi IV, when we measure electronics as a percentage of vehicle cost. Practically every new function envisioned in the years ahead will depend on electronic technology. Clearly, customers are interested in the function of various features and the role of electronics is largely transparent.

Panelists forecast a wide range of new electronic-based features, including voice-activated controls, drive-by-wire, collision-avoidance systems, electronic keys, and a variety of advanced displays. Measured as a percentage of various vehicle subsystem cost, electronics will be dominant elements in driver information and entertainment systems, and less significant, but still important, in the powertrain and chassis/suspension. With expanded overall vehicle electrical demands, a majority of our panelists expect an increase in system voltage during the next decade. Systems with 24 volts, or split systems (12/24 or 12/48) are viewed as likely.

These panelists view multiplexing as an important technology, but again expect lower penetration rates than observed in past Delphi studies. They forecast that 20% of passenger vehicles by the year 2000 will use at least one multiplexed system in such key areas as the steering column, door interfaces, entertainment, and lighting controls. Of course, less visible forms of multiplexing may be imbedded in a relatively large fraction of electronic control elements.

I. GENERAL VEHICLE FEATURES, DESIGN, AND STRATEGIC PLANNING FACTORS

TECH-1. What is your estimate of retail fuel prices per gallon in the U.S. for the following years? *(In constant 1988 dollars; that is, without adjusting for inflation.)*

Gasoline	Retail Price per Gallon					
	Median Response			Interquartile Range		
	1990	1995	2000	1990	1995	2000
Unleaded Regular	$1.05	$1.20	$1.40	$1.00/$1.10	$1.10/$1.35	$1.30/$1.70
Unleaded Premium	1.20	1.35	1.60	1.15/1.25	1.27/1.50	1.50/1.80

DISCUSSION

Vehicle fuel prices are a key factor influencing practically all automotive products and marketing decisions. This fuel-price question has been asked in all previous Delphi surveys, first to establish a base of reference and secondly as an example of format for all subsequent Delphi V questions.

Unleaded regular gasoline prices are forecast to be $1.20 in 1995 and $1.40 by the year 2000. As indicated by the interquartile ranges for these median responses, there is a high degree of consensus. The interquartile range (IQR) shows that 50% of the panelists predict a 1995 price in the range of $1.10 to $1.35 per gallon. The interquartile range for the year 2000 shows that 50% of the panelists estimate between $1.30 and $1.70. While the interquartile range for the year 2000 is somewhat broader than the range for 1995, it is still reasonably narrow for a 12-year forecast.

SELECTED EDITED COMMENTS

- A $.05 per gallon increase will be due to required changes in on-highway diesel fuel specifications to meet the 1994 emission regulations. This will put increased costs into gasoline.
- Prices will be basically flat, assuming U.S. government does not increase tax to generate revenue.
- Because of the political unrest in the Middle East, the world can expect one more fuel crisis in the next decade.
- Oil supply reserves data will be believed, i.e., oil really is a finite resource after all.
- Crude oil availability will begin to rather slowly shrink in the next five to ten years.
- Depends on Middle East stability and collective pricing, on OPEC and other oil-producing countries.
- During the 1990s, a renewed recognition of scarce oil supplies will occur. Oil shale and other more expensive oil supplies will be developed.
- Assuming no major shift in supply due to the Middle East situation, fuel costs will just keep pace with inflation.

- Fuel prices will remain sensitive to geopolitics and added taxation loading. Methanol/ blends usage will rise.
- Fuel prices economically stable. Average two-percent increase per year.
- Full impact of more fuel-efficient vehicles will be evident in 1990s resulting in decreased demand.
- A gradual demand increase, primarily in the Third World, will impact supply and demand.
- "Revenue-enhancing" taxes likely to be applied short term. Lower cost, more efficient gasohol, and octane enhancing chemical technologies will tend to offset price increases later in the next decade. Iran and Iraq's need for cash will cause overproduction and keep prices down for the short-term.
- A return to fuel-efficient cars will be caused by a price increase around 1995. The fuel-efficient cars will then curtail demand and keep prices steady.
- Combined tax increases and oil shortages will result in significant increases in fuel prices.
- There will be a government fuel tax to balance budget.
- I expect another shortage in the mid-1990s to remind us to conserve—again! Prices will then stabilize.
- Increased U.S. dependence on oil imports (rising above 50% mid-1980s) will result in concerns about national security, etc.
- Vehicles will have less demand for premium fuel due to engine construction/design changes during the next decade.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in close agreement regarding the per-gallon price of both unleaded regular and unleaded premium gasoline for the years 1990 and 1995. Differences that exist in the forecast are within the range of 2 to 5 cents per gallon. For the year 2000, the OEM panelists forecast $1.50 for unleaded regular and $1.70 for premium; the supplier panelists forecast $1.40 and $1.60, respectively.

COMPARISON OF FORECASTS: MKT-6

The following table shows the forecasts of two panels for fuel prices in the years indicated. As is illustrated in the fuel-price forecasts, there is no significant disagreement between the two panels.

Gasoline	Technology Panel			Marketing Panel		
	1990	1995	2000	1990	1995	2000
Unleaded Regular	$1.05	$1.20	$1.40	$1.03	$1.15	$1.25
Unleaded Premium	1.20	1.35	1.60	1.15	1.28	1.40

TREND FROM PREVIOUS DELPHI SURVEYS

Variations of this "price-per-gallon" question were asked of all panels in every previous Delphi. This has resulted in the accumulation of trend data since 1979. The following table shows median responses from four previous Delphis on the question of fuel prices. Each of these forecasts is in current dollars at the time of the survey. Adjustments to 1988 dollars for each forecast are also shown.

	Forecast for 1990				Forecast for 1995		Forecast for 2000	
Unleaded Gasoline	1979 Delphi I	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V	1987 Delphi IV	1989 Delphi V
Price*	$2.50	$3.00	$1.60	$1.20	$1.40	$1.28†	$1.75	$1.50†
1988 CPI**	4.07	3.90	1.90	1.30	1.51	1.28	1.89	1.50

*Dollars at time of survey.

**Adjusted to 1988 consumer price index (CPI).

†Delphi IV specified only unleaded gasoline. Prices per gallon shown for Delphi V forecasts are an average of the difference between unleaded regular and unleaded premium.

STRATEGIC CONSIDERATIONS

The forecasts for future gasoline prices continue a trend toward moderation first evidenced in Delphi III. The present forecasts for 1995 are significantly less than those of Delphi IV. We would like to reiterate a comment made in earlier forecasts that this change in the forecasts of the energy future is not an indication of a failure in the reliability of our previous Delphi panelists (many of whom are panelists in Delphi V); but rather a warning that even experts cannot be certain of a future which, in this specific case, is determined by international politics as well as free-market forces. Of course, with possible increased state and/or federal gasoline taxes, significant changes could well occur in the Delphi V forecast.

In a general sense we can understand the greater optimism concerning future energy stability than was envisioned in prior years because of a number of significant developments.

1. Even with the significant possibility of a major Middle-East war occurring within the last several years, real energy prices actually dropped, indicating that, at least for the foreseeable future, there is significant global petroleum supply. Furthermore, no matter how unpredictable energy-producing countries might be, their petroleum still manages to find its way to markets throughout the world.
2. Increased cash-flow requirements on the part of energy-producing nations necessitate pumping increasingly larger quantities of petroleum.
3. Progress in alternative fuel technology, particularly the use of methanol, seems to be causing concern within the major energy-producing nations that any significant disruption of petroleum supplies could accelerate the move toward alternative fuels and thereby diminish the value of their petroleum resources.
4. Continued improvement in overall fleet fuel economy.
5. Increased stability and reliance on market-oriented economies in communist countries would promote world-wide political and, therefore, economic stability. This should remain a valid assumption irrespective of recent turmoil in the People's Republic of China.

Even with these factors in mind, we must consider that energy will remain, to a certain extent, a volatile commodity in the world marketplace, subject to any number of potential dislocations.

TECH–2. What percent of North-American-produced vehicles will be capable of using the following alternate fuels by the years indicated?

Alternate Fuels	Median Response			Interquartile Range		
	1995	2000	2005	1995	2000	2005
Neat methanol to 15% HC/85% methanol (M85)	2%	8%	12%	1/5%	5/15%	5/25%
Full-range of methanol-gasoline blends (flexible fuel vehicles)	2	10	15	1/5	5/15	8/25
Low-octane gasoline (<75 Octane)	0	1	1	0/1	0/5	0/10

SELECTED EDITED COMMENTS

- Auto companies will need a major incentive to change from current gasoline properties.
- In my estimates, flexible fuel vehicles (FFV) are also included in the numbers shown for "neat methanol to 15% HC/85% methanol."
- FFV will come first. M85 (85% methanol) vehicles will follow.
- If need arises, the percentage could be up to 50% of new vehicles, per Brazil's experience.
- Low-octane gasoline engines are not an economic use of available oil resources. Refinery/engine efficiency tradeoff indicates that 91 octane is close to optimum.
- Neat methanol will be limited to captive fleets. CAFE credits will drive FFV penetration.
- Neat methanol is a potential safety hazard at low temperature; low vapor pressure means air/fuel vapor in tank is combustible.
- Not much change expected unless oil shortages or cost increases occur.
- Percentages based on annual production of 8 million light-duty vehicles.
- Recent articles on alcohol emissions show harmful emissions.
- The speed of methanol application depends on two factors: (1) artificial government incentives (fuel economy credits), and (2) success of direct-injection technology in overcoming cold-start problems.
- The technology exists to do any of these. It will depend on the world energy condition.
- Total vehicles will be in the range of 10% to 18% in 1995 using any of these alternate fuels. Many applications are not mutually exclusive, i.e., small utility/commercial vehicles.
- Use of methanol will result from legislation for air quality and other political ends, rather than economic viability. Not clear why low-octane fuels would be needed/available. Industry would respond if market demand exists.
- Why would anyone want to use 75-octane gasoline?

MANUFACTURER/SUPPLIER COMPARISON

A significant difference exists between the manufacturer and supplier panelists regarding the percent of North-American-produced passenger vehicles that will be capable of using alternate fuels. These differences are illustrated in the following table.

Alternate Fuels	Forecast for 1995		Forecast for 2000		Forecast for 2005	
	OEM	Supplier	OEM	Supplier	OEM	Supplier
Neat methanol to 15% HC/85% methanol	3%	2%	10%	5%	20%	10%
Flexible fuel vehicles	2	2	10	8	15	12
Low-octane gasoline	0	0	0	2	0	2

TREND FROM PREVIOUS DELPHI SURVEYS

Although three previous Delphi IV questions addressing the methanol issue are not directly comparable to the present Delphi V question, there was significant information presented that should lend to a more in-depth perspective of industry-wide concerns regarding alternate fuels.

In the 1987 Delphi IV the following question was asked: "What percentage of gasoline will use the following for octane enhancement for the year 1990 and 1995?" The panelists at that time forecast that *methanol* would be used as an additive in 10% of gasoline in both 1990 and 1995. They also forecast that *ethanol* would be used as an octane enhancer in 10% of gasoline in the same years. Additionally, by 1995 it was forecast that other additives such as MTBE and MMT would be used to enhance octane in 10% of the gasoline produced. The remaining gasoline would contain no additives but would be subject to additional refining.

Another question directed at the production of methanol and other alternate fuels reinforced the primacy of methanol as an alternative to gasoline. The question and results are as follows:

What is the likelihood of production in significant quantities of each of the following IF there is a major and continuing interruption in international petroleum supplies?

	High	Moderate	Low	Unlikely
Methanol from natural gas	35%	48%	12%	5%
Methanol from coal	33	36	24	7
Natural gas	22	33	38	7
Petroleum-like fuels derived from coal liquids	19	33	41	7
Ethanol	18	42	35	5
Liquid petroleum gas (LPG)	17	34	47	2
Hydrogen	0	9	40	51

In Delphi III, panelists were asked to rank possible vehicle fuel alternatives on a scale from 1–4, with 1 equal to most likely. Considering the differences in ranking procedure, panelists from both Delphi III and Delphi IV were in agreement in considering methanol from coal or natural gas to be in the very high to moderate range. Delphi III panelists considered the likelihood of petroleum-like fuels derived from coal liquids to be in the moderate range, whereas Delphi IV respondents were more in the range of low to moderate.

An additional question regarding the principal advantages and disadvantages of methanol was asked in Delphi IV. Relevant data and responses are presented as follows.

What are the principal advantages and disadvantages of METHANOL gasoline blends from both a vehicle and a fuel perspective?

Methanol: Fuel Perspective

Advantages	% Total Responses	Disadvantages	% Total Responses
Availability at a reasonable/ lower cost	65%	Volatility control economics (handling systems/fuel storage problems)	35%
Ease of blending and octane enhancement	35	Water absorption tolerance (hydrophilic nature) of methanol	25
		Cost	20
		Blending problems	20

Methanol: Vehicle Perspective

Advantages	% Total Responses	Disadvantages	% Total Responses
Octane enhancement and power improvement	95%	Corrosive nature of methanol/ materials incompatibility	55%
Reduced exhaust gas emissions	5	Increased fuel consumption, shorter driving range, and necessity for increased tank volume	45
		Other Comments: Cold weather starting problems	

Representative Responses

Methanol—Fuel Perspective

Advantages:

- Relatively cheap, seems to work OK.
- Should be possible to provide substantial quantity at reasonable cost. U.S. a source of raw materials. Can be blended.

Disadvantages:

- It depends on methanol/gasoline ratio.
- Blends limited to 10% without special processing. May present problems in contamination in handling and distribution.
- Economy and performance benefits are not fully exploited.
- Aldehyde emissions.
- Low energy density. Volatility degradation/hydroscopicity.
- Requires changes in materials to handle it. More tank volume required. Low heating value per pound.
- Low caloric value. Safety (invisible flame and handling problems).
- Explosive mixture possible in fuel tank.

Methanol: Vehicle Perspective
Advantages:
- Higher power output, higher compression ratio for higher energy efficiency.
- Potential for lower NOx and CO—higher aldehydes.
- Differing emission generation will result in engine reoptimization. Provides high octane performance.

Disadvantages:
- Lowest heat of vaporization; requires larger fuel tank capacity, materials compatibility.
- Engine components must be compatible. Engine controls must be adaptable.
- Low trip length per unit of fuel.
- Hose swelling.
- Lower heating value, methanol not competitive with cheap oil.
- Requires pressurant for cold start (M-85).
- Fuel system corrosion and deposits, volatility problems.
- Dissolves plastics, rubber, and magnesium.
- Adverse effects on metal and elastomeric parts used in existing fuel systems.
- Materials incompatibility. Evaporation canister deterioration. Shifts in stoichiometry.
- Corrosive effects on polymers.
- Problems with reliable cold starting.

Discussion

The responses to this Delphi IV question are rather straightforward and predictable. From a fuel perspective, methanol availability is an important advantage as well as its general ease of blending in low percentages and the octane improvement. Handling and distribution concerns are important, as are the challenges of higher levels of water absorption, cost, and blending problems. From a vehicle perspective, the panelists generally foresee that octane enhancement, and therefore potential power and efficiency improvement on a BTU basis, as significant with some level of emissions reductions. Disadvantages focused heavily on materials problems as well as higher fuel consumption because of the lower energy content of the fuel on a unit-volume basis, and cold weather starting problems.

The same question was asked of Delphi IV Materials panelists. The only difference between the two panels was in the advantages of methanol from a vehicle perspective. Whereas slightly over one-half of the materials panelists considered octane enhancement and power improvement the principal advantage, the Technology Panel was nearly unanimous in supporting this option.

STRATEGIC CONSIDERATIONS

With growing concerns regarding the energy future in North America, there is increasing interest in non-petroleum-based fuels or fuels with somewhat different properties than presently commercially available. There appears to be a general consensus that in the long term we will move toward a methanol fuel strategy replacing petroleum-based fuels. It is evident from the panelists' responses that toward the latter part of the next decade, an increasing fraction of vehicles will be equipped to handle methanol or, perhaps more appropriately, a full range of methanol/gasoline blends, a so-called "flexible fuel vehicle" (FFV). With the present pace of development in this area, it is conceivable that these forecasts could expand rather dramatically, depending on external energy scenarios (e.g., government pressure) and the type of technology that emerges. In any event, this is an area that should be watched very carefully because of the broad impact it would have on the entire fuel management system, both with respect to controls as well as system materials. A strategic issue with regard to these technologies is that their very availability should restrain petroleum-producing nations from becoming overly aggressive with respect to petroleum pricing and availability.

Two additional concerns regarding the development of a national methanol-based fuel strategy are:

1. Ability to produce and distribute sufficient quantities of fuel.
2. The net consumer cost must be similar to gasoline in terms of purchase price, operations costs, and convenience.

We hope that government agencies and vehicle manufacturers will work in a cooperative manner in setting a public agenda for the area of alternate fuels.

TECH-3. Of the passenger-car fuel-economy improvement scheduled for 1995 and 2000, what percentage of the improvement will come from the following factors?

Improvements	Percent of Total MPG Improvement			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Improved engine efficiency	25%	24%	20/28%	19/28%
Improved drivetrain efficiency including transmission improvements	25	25	20/25	20/27
Weight (but not size reduction through increased use of lightweight materials)	18	20	15/20	15/23
Improved aerodynamics	10	10	10/15	5/15
Improved accessory drives	10	10	5/12	5/12
Downsizing	5	5	0/6	0/6
Reduced tire rolling resistance	5	5	4/6	3/6
Reduced performance (lower power/wt. ratio)	0	0	0/0	0/0
Others*	2	1		

*Other factors for fuel economy improvement incorporated in the percent *Other* category are as follows (percent/year are individual responses):

	1995	2000
Capability on alternative fuel operation	0%	3%
Composite structures	15	25
Electronic control systems	10	13
Drive-by-wire electronics	5	15
Electric cars	15	20
Fuel additives	4	0
Starting quickly	5	5

Additional panelists' suggestions without percent forecasts are as follows: Continuously-variable transmissions; non-piston IC engines; ceramics and encapsulated engines; elimination of drive belts; brushless alternators and DC motors as high voltage; low-loss accessories; brake and transmission loss regeneration.

SELECTED EDITED COMMENTS

- "Downsizing" is over. Vehicles will become larger.
- Diminishing return on further engine R&D. Broader penetration of CVT into the automatic transmission segment. Novel accessory drives to improve accessory utilization and permitting accessory downsizing.
- Electronic controls will play a significant role to improve engines, drivetrains, and accessory drives.
- Expect major new engine controls, combustion advancement. Major improvements in drivetrain due to transmission revisions and friction reduction in powertrain. Expect more efficiency in accessories like air conditioning.

- I'm basing prediction for drivetrain on what Japanese have done across models since they stepped up engine development. Good solid engine advancements are less than five years old in the U.S.
- Improved engine efficiency will be achieved primarily through use of higher power density engines.
- Room for major improvements in accessory drives and components. Driving force will be freeing up of more power for performance without going to larger, hungrier engines and fuel systems.
- Streamlining has gone as far as practically feasible in several 1989 models, and, aside from dream cars, will not contribute so much in the future. Engine efficiency will be the area of greatest improvement.
- Systems approach to optimization will become a major factor. Interactive tradeoffs will provide significant product optimization.
- Vehicles will become larger. Weight reduction will be achieved through increasing utilization of composites.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in complete agreement on over 80% of the forecasts. The remaining forecasts differed by no more than 5%.

TREND FROM PREVIOUS DELPHI SURVEYS

A significant consistency is observed between Delphi IV and Delphi V 1995 forecasts for factors affecting fuel economy improvement. A historical review of the results of Delphi IV when compared with those of Delphi II and Delphi III indicate an evolution in the pattern of technology-driven developments affecting fuel efficiency. Downsizing, which was the leading improvement factor in Delphi II (forecast at 30% for 1990), declined to 6% in Delphi IV and 5% for 1995, in both Delphi IV and V. In retrospect, this does not mean that the earlier forecasts were erroneous but rather that by the time of the later forecasts, much of the relevant downsizing had already taken place. What is of interest is that the four factors that ranked the highest in the current Delphi (engine and drivetrain efficiency, weight, and aerodynamics) achieved similar ranking in Delphi III and IV.

Improvements	Forecast for 1990			Forecast for 1995	
	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
Drivetrain Efficiency	10%	23%	22%	22%	25%
Engine Efficiency	15	23	23	22	24
Weight	20	17	18	20	20
Aerodynamics	10	12	12	11	10
Tire Resistance	5	6	6	5	5
Downsizing	30	14	6	5	5
Others: Accessory Drive	10	5	13	15	11

STRATEGIC CONSIDERATIONS

There is a strong similarity between the results of the current forecast and those of Delphi IV. These two Delphis represent a rather dramatic shift from earlier Delphis. It is clear that the industry has made the most of the more obvious, straightforward changes to improve fuel economy and must now concentrate on the more challenging tasks of improved engineering and design, particularly in the powertrain. The data is also consistent with other results in the study suggesting that the move to smaller passenger cars has slowed considerably. Technology, in general, is expected to be a more prominent factor in future fuel economy gains. The relatively high rating for weight reduction is an indication that we may be on the threshold of a materials revolution with plastics, magnesium, aluminum, new ways of using steel, and various types of composites.

Improved accessory efficiencies are emerging as an important area. Features such as electric and variable-speed belt drives and redesigned components such as air conditioning compressors, water pumps, etc. offer significant promise for future gains.

Obviously, with the surge of environmental pressure related to such factors as the greenhouse effect, photochemical smog, degradation of the ozone layer, and renewed energy availability uncertainties, the demand for fuel economy improvements could accelerate significantly.

TECH-4. It has been said that world-class cost and quality are prerequisites for competing within the various vehicle segments. From the perspective of the traditional domestic vehicle manufacturer, what will be the key elements that will form the basis of competition past 1990?

The many thoughtful yet diverse responses to this question consist of suggestions that appear to overlap but may, in a different context, be considered separately. For example, *styling* may encompass comfort and ergonomics; *customer service and satisfaction*: dealer and customer relations and shorter delivery time to dealers; *reliability/durability*: reduced maintenance; etc. In order to avoid any overly extensive listing of suggestions, the following response categories have been established. Also, this is a question where the comments and responses represented below should be considered an integral part of the analysis.

Basis of Competition: Key Elements	Percent of Panelists
Quality	43%
Cost	39
New technology/product innovation	32
Styling	29
Responsiveness to market	20
Customer service and satisfaction	15
Performance	13
Reliability/durability	13
Safety	7

REPRESENTATIVE RESPONSES

- World-class designs and materials with attendant processes to provide product with minimal inventory. Products must be designed and proven to bring the life of a vehicle in better balance (i.e., eliminate over-design and over-specifying) and at the same time upgrade the components we consider service items today to last the life of the vehicle. In other words, everything should wear out at the same time, within the limits of component variability.
- Timing and flexibility are required to respond to customers' needs in every segment offered.
- A mindset that there can be no compromise of quality.
- Ability to bring a vehicle to market quickly and to present new vehicles to challenge rapid change by Japanese, either import or New Automotive Manufacturers (NAM). I believe it will be imperative to get work rule and outsource concessions from the UAW to meet the relentless cost challenge by the NAM and imports. The change in the yen/dollar relationship could possibly be helping Japanese in their resolve to lower cost.
- Better and more trusting relationships with quality suppliers to help find innovative ways to reduce cost—not standard attitude of squeezing suppliers or rewarding low bidder rather than innovator.
- Continued excellent quality (it will be expected). Improved quality of service at dealer level; it has not kept pace with engineering/manufacturing quality gains. Faster response with new vehicles.

- Correcting problems will not be enough. Domestic vehicles will need to have positive appeal. Of course, costs will continue to be an essential element of competitiveness. The low-cost producer has the greatest number of options.
- Cost and quality will continue to be critical. One important facet will be convincing the American public that the U.S. automakers are leading in technology again rather than simply reacting to the Japanese. Distinctive styling will also be an important factor if the U.S. automakers cannot otherwise successfully differentiate their products.
- Cost and quality will continue to be prerequisites. Quality, of course, includes advanced features, sales, and service. The real competition may come from other modes of transportation. I would suggest increased emphasis on automated expressway transportation.
- Perceived value. Judicious application of "real value" features such as four-wheel ABS, traction control, etc.
- Customer perception of the manufacturers' commitment to quality. Actual quality improvements to meet the higher levels of Japanese quality. Implementation of process controls and product designs which reduce actual cost through improved quality.
- Customer satisfaction via things that excite them. Outstanding performance without noise or vibration.
- Effective implementation of technology.
- Flexibility of companies to meet customer needs through differentiation in styling and features. JIT delivery of vehicles to dealer, reducing dealer car inventory.
- Flexible manufacturing to meet market demands and shifts. Ability to integrate worldwide resources effectively.
- Fresh, innovative styling. Unquestioned 100,000-mile durability. Advanced powertrain, chassis, and interior technologies that make operation more efficient and safer.
- Global flexibility in production, technology derived to address global applications for economies of scale, business base solidified by acquisition, partnership or joint venture allows amortization of all design and manufacturing costs.
- I anticipate that the "traditional domestic vehicle manufacturer" may not exist in the mid-late 1990s. But, in order of importance, the key elements of competition will be: cost, quality, customer service (sales and vehicle servicing staff), and a vague, all-encompassing yardstick called "Corporate Reputation."
- Labor costs.
- Luxury segment: comfort features, styling for image, safety. Mid-range sedans: quality, reliability, service for handling warranty problems/complaints/parts supply/repairs. Economy and sub-compacts: quality, competitive price, fuel economy, service.
- More rapid transition of new technologies to market. Increased commitment to long-term R&D efforts. A greater willingness to enter pre-competitive R&D consortia. Develop a closer understanding with the government agencies, i.e., more closely emulate the Japanese way of business.
- Price will be high—content will be at extreme, complex, technical levels. May see ability to adapt new technological innovations to older vehicles as important.
- Price will take a significantly increasing role. Features not gimmicks, but usable customer features that represent real benefits. Responsiveness—ability to predict and adapt to changing moods, needs, and trends.
- Insurance.
- Change the culture of the U.S.-built car dealers from adversarial to cooperative.
- Vehicle systems integration—literally an electronically systematized vehicle.

- Quality in its broadest sense including satisfiers—"Things gone right"—cost will be a key factor. The combination of cost and quality (value) will be the prime customer driver. Cycle time will be a competitive issue. Short cycles will represent a significant advantage.
- Quality—the prerequisite. Cost—with thirty competitors, cost must be controlled—plan ahead! Customer-perceivable technology, not technology for technology's sake.
- Quick response to market with specialty vehicles. These would include special vehicles off existing platforms (convertibles, GT versions, etc.) and new vehicle platforms. Many of the markets will become small, "niche" market segments.
- Retail cost (reflecting realistic profits), demonstrated quality—no problems for 100,000 miles; traditional values—minimum Mickey Mouse gadgets, straightforward selling methods—no more games with the dealers. Buying a new car is the single most distasteful experience today.
- Style, ergonomics, delivering "fun to drive" and "more than expected" by customer. Customer (driver) always in control, i.e., no surprises, no unusual noises, no driving anomalies.
- Styling—aerodynamics, low hoodline. Durability—other than warranty (i.e., guaranteed cleanability for interior). Segmentation—ability to create new products from existing platforms, fast.
- Supplier of complete systems or modules. Advanced technological capabilities. Tier 1 supplier minimum size will be $500–$750 million. In the traditional sense, there will be very little "competition." The competition will be internal, i.e., can you continue to reduce cost and remain profitable?
- The customer expects the product to be right the first time. Ergonomics—man/machine interface should feel comfortable. Vehicle operation has to have a natural feeling. More attention must be paid to the comfort of the passengers.
- Those manufacturers who are not cost and quality competitive will not survive! The manufacturers who will excel are those who: (a) lead technologically; and (b) can rapidly respond to market "niches" and changes. These two points indicate that technology must be applied not just to the product, but to manufacturing where flexibility and rapid change (while maintaining high quality and low cost) will be key. Much more emphasis on special low-volume models.
- World-class quality, cost, features (active suspension, electronic-controlled transmission, closed-loop engine controls, four-wheel drive, anti-lock braking system standard, three- and four-valve engines), shorter product development cycles.
- Comparison by the consumer of the car as a total package for a price. Not a "base" car (stripped) with add-ons plus, plus, plus. A car with few features in its market segment is a negative message and negative perception of the manufacturer.
- Worldwide sourcing of components; fairness in trade, regulations, and foreign government subsidies.
- Innovative new customer-driven vehicle concepts, i.e., the next minivan.
- Appearance; fit and finish; give to the customer more than expected; all items function like a watch.

STRATEGIC CONSIDERATIONS

While a wide range of responses to this question were generated, there was a consensus with regard to the thesis presented in the problem statement, i.e., that world-class cost and quality are prerequisites for both manufacturers and suppliers in the automotive industry. In point of fact, both world-class cost and quality are considered as just entrance tickets to the international competition of the future. We have attempted to summarize responses in individual categories, although this is done with some reservation considering the considerable overlap that can occur in the interpretation of categorization. Quality and cost head the list. The very clear implication is that the panelists see these as both fundamental and essential features of competitive products.

Many of the traditional value or quality factors the customer will use to differentiate between products will lose their effectiveness as differentiators when essentially all of the manufacturers' products achieve equality. For example, fit and finish, crashworthiness, reliability, structural integrity, and many other factors are becoming similar across the broad spectrum of automotive products. As this becomes evident to the customer, we envision four areas that will become of increasingly crucial importance. They are new technology with high-perceived value, rapid response to market opportunities, total customer satisfaction related to sales and service, and style/fashion, i.e., how the car literally feels when one is "wearing" it.

The responses provide a clear indication that the intensity of competition will accelerate in the years ahead and that successful industry participants will be those able to establish strong relationships with their customers. Systems-based thinking is necessary to success in this competitive environment.

It is also apparent that manufacturers and suppliers will have to think increasingly in terms of full life-cycle management of their product, and not just to the end of the warranty period. Management of the total ownership spectrum, including recycling, will add a major new dimension to both manufacturers' and suppliers' responsibility and must be considered within the context of cost and quality issues.

TECH–5. In the following categories, what is your expected ten-year current standard trend and/or likely new areas of legislative activity.

Categories	Government Regulatory Trend		
	More	Same	Less
Occupant Restraint/Interior Safety: Light Truck	92%	8%	0%
Vehicle Emissions: Light Truck	88	11	1
Vehicle Integrity/Crashworthiness: Light Truck	87	12	0
Vehicle Integrity/Crashworthiness: Passenger Car	85	15	0
Occupant Restraint/Interior Safety: Passenger Car	83	17	0
Vehicle Emissions: Passenger Car	76	23	1
"Lemon Laws"	61	37	3
Noise: Light Truck	51	49	0
Product Liability	51	43	6
CAFE: Light Truck	44	47	9
Noise: Passenger Car	38	61	1
CAFE: Passenger Car	30	58	12

DISCUSSION

It is readily apparent that, in contrast to Delphi IV, the Delphi V panelists expect a dramatic increase in U.S. governmental legislative activity in every area specified. In over two-thirds of the areas surveyed, 0–1% of the panelists did not foresee any trends toward a lessening of governmental regulation or legislation. Only in the areas of noise and passenger car CAFE requirements did at least one-half of the panelists expect some degree of the status quo.

In general, the new areas of legislative activity cited by the panelists for light trucks were similar to those for passenger cars.

In their comments regarding product liability, the panelists were equally divided between expecting a limit in liability awards and expecting an increase in product liability activity. The primary new areas for product liability activity cited by the panelists were related to electronics and braking systems.

A breakdown of specific areas of activity as well as representative responses for each category are listed following the general *Trends* analysis.

COMPARISON OF FORECASTS: MKT–3

The Technology and Marketing panelists were in general agreement regarding the prioritization of automotive-related areas likely to see federal regulatory and/or legislative activity. In rank-order the top six categories for Marketing panelists are in accord with the first six categories discussed by the Technology panelists.

GENERAL TRENDS ANALYSIS

Forecasts for More Regulation in:	Trends in Government Regulation		
	1984 Delphi III (through 1990)	1987 Delphi IV (through 1995)	1989 Delphi V (through 2000)
Vehicle Emissions	9%	14%	76%
Safety	27	36	85
Fuel Economy (CAFE)	19	8	30
Crashworthiness	N.A.*	19	85
Occupant Restraint	N.A.	50	83
Noise	N.A.	23	38
"Lemon Laws"	N.A.	56	61
Product Liability	N.A.	49	51

*Data not available.

TYPE OR DIRECTION OF REGULATION FORESEEN

Vehicle Integrity/Crashworthiness	Percent Panelists Suggesting an *Increase* of Standards
Passenger Car	
Side Impact Protection	40.0%
Rollover Protection	14.0
Passive Restraints	9.5
Thirty-Five-MPH Barrier Standards	9.5
Friendly Interiors	7.0
Rear-Seat Passenger Protection	5.0
Collision Avoidance	5.0
Others (see *Representative Responses* below)	10.0

Representative Responses

- Repairability cost and injury protection.
- Merge car/multi-purpose vehicle.
- Amendments to keep up with new technologies.
- Thirty-five-mph barrier.
- Rollover; non-centered barrier impact test.
- Side impact emphasis, fire control (both in avoidance and retardation).
- Energy-absorbent structure, active occupant restraint, control/handling improvements to avoid crashing.
- Mandatory ABS brakes.
- Unbelted occupant protection.
- Damageability—cost impact.
- Side impact, rear-seat space after rear moving test.
- Clarification and procedural changes as opposed to increase or more stringent.
- Expect requirements/testing to become more complex.
- Second hit protection.
- Passive restraints—interior designs will accommodate better means of avoiding side penetration.

Vehicle Integrity/Crashworthiness	Percent Panelists Suggesting an *Increase* of Standards
Light Truck	
Same as Passenger Car Standards	35%
Rollover Protection	29
Side Impact Protection	21
Front Barrier/Bumper	8
Passive Restraints/Airbags	7

Representative Responses
- Side barrier, rollover, higher speeds, airbags.
- Getting closer to passenger car standards.
- More events: side impact, unbelted occupant, corner, impact, rollover.
- Rear-moving barrier.
- Similar to car (repairability, cost, and injury protection).
- Passenger and commercial vehicle (light trucks) will separate.
- Club cab passenger protection.
- Bumper standards same as passenger car.
- The increasing number of passenger-oriented vehicles which carry a truck classification is already recognized by government and safety groups. Ultimately, they will have safety standards equivalent to passenger cars.

Product Liability

In their comments regarding product liability, the panelists were equally divided between expecting a limit in liability awards and expecting an increase in product liability activity. The primary new areas for product liability activity cited were electronics and braking systems.

Representative Responses / Comments
- Electronic drive-by-wire could be a problem.
- Government not up to getting realistic control.
- Product liability lawsuits (and also various malpractice suits) will be limited in award amounts.
- "Electronic" liability issues.
- No change, but expect more activity and expense under current laws.
- See a trend toward a more logical approach to this, i.e., less "deep pocket" and limitation in pain/suffering and punitive damages.
- General liability will reach a crisis level and drop.
- Lawyers will find new areas.
- Separate design and performance liability.
- Warranty coverage language will be challenged, clarified.
- Regrettably, product liability will increase.
- Look for shift interlock devices.

Occupant Restraint/Interior Safety	Percent Panelists Suggesting an *Increase* of Standards
Passenger Car	
More Passive Restraints (including airbags)	40%
Active Restraints (including rear-seat occupant restraints/shoulder belts)	21
Friendly Interiors	18
Side Impact Protection	14
Airbags Banned/Ineffective	7

Representative Responses
- Review of airbag effectiveness.
- Higher-speed survivability.
- Shift to airbags.
- Intrusion, "A"-pillar, glass laceration.
- Better back seat.
- Side impact, knee injury.
- More passive protection.
- Energy-absorbing armrests, etc.
- No change beyond what is now on books.
- Airbags, front and rear seats.
- Inflatable restraints for all seats.
- Emphasis on driver behavior.
- Rear-seat occupant restraint.
- Front passive/rear outboard lap-shoulder.
- Mandatory rear-seat three-point, airbags.
- Automatic seat belts.
- Side ejection protection.
- Occupant injury criteria.
- Rear outboard lap-shoulder.

Selected Edited Comments

• Perhaps there should be different responses for Democratic and Republican administrations!

• Friendly interiors will ban airbags (bad service record versus cost). Expect airbags (as known today) to be judged ineffective.

Occupant Restraint/Interior Safety

Light Truck

Representative Responses
- Higher-speed survivability.
- Increased awareness and demand for safety features.
- Rear outboard lap-shoulder.
- Passenger car and light truck rules will be the same because the light truck is being used to replace the car (light truck includes vans, etc.).

Vehicle Emission Control

Passenger Car	Percent Panelists Suggesting an *Increase* of Standards
On-Board Refueling/Vapor Recovery and Control	28%
Hydrocarbons	18
Cold-Start Pollutant Standards (non-specific)	16
Aldehydes	11
California-like (Local) Emission Standards	9
Methanol Fuel Requirements	7
Carbon Dioxide (CO_2)	7
Oxides of Nitrogen (NO_x)	4

Representative Responses

- Concerns with heat release and CO_2 (could end horsepower war). Required due to concern for upper atmosphere and heat.
- CFC, aldehydes.
- Ability to use methanol fuels.
- Potential carcinogens.
- Ozone control.
- Methanol emission requirements.
- Regional tightening of standards, more field testing.
- On-board vapor recovery will be more stringent.
- 0.4 NO; 0.25 HC.
- Periodic recertification.
- Specific hydrocarbon health effects.
- 100,000-mile certification.

Vehicle Emission Control

Light Truck	
Same as Passenger Cars	30.0%
Diesel Particulates	19.0
On-Board Refueling/Vapor Control/Recovery	14.5
Aldehydes	11.0
Carbon Dioxide (CO_2)	11.0
Hydrocarbons (HC)	3.5
Sulfur Oxides (SO_x)	3.5
NO_x	3.5
None	4.0

Representative Responses

- Fuel vapor emissions.
- Freon (CFC).
- Federal standards to reach California standards.
- Broader coverage above 10,000 lb GVW.
- Diesel particulate standards for 1994 will be a challenge.
- Formaldehyde, refueling emissions, cold temp CO.
- Hydrocarbons and cold CO; more like passenger cars.
- Light trucks will match cars one to one.
- Will be the same as passenger cars.

SELECTED EDITED COMMENTS

Vehicle Emissions

Passenger Car and Light Truck

- "Running loss" hydrocarbon emission legislation likely within five model years.
- Strong support from EPA and NHTSA for utilization of multi-fuel vehicles (FFV). California is a strong advocate of methanol as a method to reduce pollution. This is now legislatively popular due to alternate fuel development.
- There will be selective areas of the vehicle that will be focused upon for increased standard requirements, e.g., fuel-fill systems to assure no fires.
- There will be increased focus and pressure to commonize vehicle emissions, safety, impact, noise, lighting, etc., standards worldwide. This will be in recognition of needs/benefits to achieve a common set of targets due to cost and marketing considerations.
- Levels may change due to competitive actions (market-driven) rather than mandated standard revisions.
- With the current ecological coverage in the media (drought caused by greenhouse effect, etc.) there is not likely to be any decrease in activity to reduce emissions.

Fuel Economy (CAFE)

Passenger Car

- Fuel economy standards for passenger cars and light trucks will be dropped (discarded). Gas prices will regulate or force fuel economy.
- The anticipated future oil shortage will keep the pressure on fuel economy standards.

Light Truck

- Political issue contingent on oil and gasoline availability and cost.

Noise

Passenger Car

- Noise standards will be locally mandated.
- This could be a trend based on what other countries do. The Japanese are studying this.
- Noise standards are just coming into vogue.

Light Truck

- A possibility of federal standards as opposed to local standards.
- Tire noise standards are likely.

Lemon Laws

- Widespread use of juries to determine factor liability with binding ruling authority.
- Legislation like this could help manufacturers as it has in Japan.
- Expect additional state rulings.
- Less attention to "lemon laws" due to better quality and systems engineering.
- Longer warranties.
- Lobbying by consumer groups will continue to put pressure on government for more stringent laws across the board.

GENERAL COMMENTS

- The gap between light truck and passenger car will continue to narrow or be eliminated. Diesel will generate unique standards.
- Standards to remain relatively stable ten years out. I see trucks and cars coming together (i.e., trucks adopting passenger car standards) as separation between cars and trucks diminishes.
- Brake standards will change due to harmonized standards with Europe in the short term and due to anti-lock application in the longer term. I predict the standards for control and stopping distance will become more stringent as ABS usage expands.
- We have government agencies whose only product, and only reason to exist, is to incorporate new standards. Therefore, there will be a continuous flow of new standards.
- There will be a gradual tightening with phase-in implementations.
- Interior air cleanliness just becoming an issue.
- Lawyers and politicians will continue to dominate the engineers.
- Overall, I don't see increases in federal standards regarding emissions, fuel economy or noise. I think the market will demand continued improvement in performance and fuel economy rather than the government.
- Other insurance-related categories (restraints, lemon laws, liability, etc.) will get continued emphasis as long as special interest groups can generate enough support for their PACs.

STRATEGIC CONSIDERATIONS

A significant increase in regulatory activity is expected by the Technology panelists. Compared to recent past Delphi forecasts, the Delphi V panel believes regulatory pressures will intensify in most areas.

The decade of the 1990s gives very indication of being similar in many respects to the 1970s with a resurgence of automotive regulation. In contrast to the 1970s, light trucks and vans are expected to be brought under comparable level of regulations similar to passenger cars. Furthermore, we anticipate a more balanced approach to automotive regulatory activity because of a more sophisticated population, greater awareness of international competitive issues, strong international regulatory pressures, a stronger knowledge base, and growing concern with non-automotive (e.g., environmental) problems.

Society will be dealing with some fundamental issues during the next decade, including the basic conflict between nuclear and fossil-based electric power generation, the greenhouse effect, deterioration of the ozone layer due to CFC emissions, a multitude of hazardous waste concerns, traffic grid-lock in urban areas, solid waste disposal, and a host of other difficult issues. We sense a shift in how standard of living is defined. Certainly during the 1980s we have been preoccupied with the accumulation of material possessions, but there is every indication that we are beginning to shift our concept of "standard of living" to one that emphasizes more "quality of life" considerations.

Prudent manufacturers or suppliers must think more strategically with regard to all regulatory issues if they are to prosper in the decade ahead. It may to be more advisable be more proactive than in the past, i.e., lead the inevitable and follow the uncertain. In fact, a smart and strategically inclined industry participant could develop a business advantage even in a more dynamic regulatory environment.

Because of the globalization of the automotive industry, it is imperative that the three major automotive production and market areas of the world (North America, Europe, and Japan) move aggressively to harmonize industrial and trade regulations. The cost of divergent standards is excessive and diverts both human and financial resources from a myriad of other challenging tasks.

TECH-6. It is generally reported that the new vehicle development process is 48 to 60 months in the U.S. and that Japanese producers' development cycle is significantly less.

TECH-6a. Please give your expectation *(in months)* of future development cycles from concept through Job One for a hypothetical reskinning of an existing platform maintaining current hardpoints.

Development	Vehicle Development Time *(months)*					
	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
High-Volume Vehicle (Production *more than* 50,000 units/year):						
United States	48	36	30	36/50	30/42	24/36
Japan	35	30	25	24/36	22/34	20/30
Low-Volume Vehicle (Production *less than* 50,000 units/year):						
United States	36	30	24	30/48	24/36	20/32
Japan	30	24	22	24/36	20/30	18/28

SELECTED EDITED COMMENTS

- The new vehicle development process time of 48 to 60 months in the U.S. is already down dramatically. What is the definition of new vehicle development process? From when concept/need is first conceptualized/identified or from a decision point that says: You have a program, go do it?
- Both are low-volume. Very difficult to answer because we (U.S. manufacturers) do not know where to start the clock. A year can be wasted in high management indecision.
- Low production takes the same time to design/engineer, test/validate as high volume. Savings in tooling insignificant at this time unless extremely low-volume.
- Low-volume is not really applicable for U.S. versus Japan nor is 50,000 a logical breakpoint.
- Low-volume vehicle production varies too much: based on percentage of new parts, volume, extent of modification, etc.
- Low-volume vehicles require the same level of engineering, unless the majority of the design is carryover from existing designs. Then 6 months or more should be saved. Additional time can be saved if soft tooling or short tooling lead times are involved.
- Volume not a factor except very low-volume. Only tool cycle impacted, shortening cycle two to six months. If program is done properly, validation remains a long lead engineering activity.

- Volume break above and below 50,000 units not significant.
- *Most* of the development time is more of the up-front design and engineering elements. I don't believe volume will make the significant difference.
- Reduced engineering design time, manufacturing process development and reduced tooling time will result from efficiencies gained from CAE/CAD/CAM integration.
- Response to market needs is critical to the survival of any auto company. The companies, wherever they are, with the shortest development cycle will succeed.
- Studies indicate that typical Japanese total program time required is about the same. However, they do appear to have a shorter implementation time with more time than U.S. on up-front engineering and sorting of alternatives.
- This is an example for the development of low-volume vehicle: In 1985, Nissan had decided to introduce "Be-1" to Japanese market as a limited edition. This is because "Be-1" had been highly appreciated by customers in Tokyo Motor Show 1985. (Platform is existing Micra.) Since manufacturing volume was estimated to be only 20,000 per two years, Nissan employed a lot of plastic material as body parts. One year later, from the decision of the manufacturing of "Be-1," it became available in the market. From this example, I have to point out the following items: (1) in order to respond to various market demand, low-volume vehicles will increase; (2) innovation in terms of engineering process, design methodology, material, manufacturing, etc. would be essential.
- Time difference is less than it appears. Japan is more thorough in planning and defining changes before beginning. The majority of difference is in U.S. revisions and changes. Critics label this inefficiency; advocates say it's flexibility. Tastes and circumstances change; customers becoming better educated and have more choices, making it much harder to "market" a mistake into a success.
- U.S. car companies will start to develop vehicles as shelf item and pick and choose to shorten the development cycle.
- U.S. technology base will permit more decisions without as many stages of prototype building and redesign.
- World design/development will collapse the Japan/U.S. spread. Technology will be common.

MANUFACTURER/SUPPLIER COMPARISON

In general, the OEM panelists expect longer future development cycles than do the supplier panelists. Their respective estimates are presented in the table below.

Development	Vehicle Development Time *(in months)*					
	Current Estimate		1995		2000	
	OEM	Supplier	OEM	Supplier	OEM	Supplier
High Volume Vehicle:						
U.S.	48	40	36	32	30	29
Japan	36	28	30	24	26	24
Low Volume Vehicle:						
U.S.	40	36	30	30	24	24
Japan	30	24	24	22	22	20

COMPARISON OF FORECASTS: MKT-20a

With the exception of "low-volume vehicle production for the year 2000," Marketing panelists generally forecast shorter development cycles for the "reskinning of an existing platform maintaining current hardpoints" than did the Technology panelists. The differences in the consensus forecasts, as well as the interquartile ranges, are sufficiently significant to merit representation in the following table. Additionally, the comments of the two groups of panelists are sufficiently divergent to warrant comparison.

Development	Marketing Panel Forecasts: Vehicle Development Time *(in months)*					
	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
High-Volume Vehicle:						
United States	40	35	30	36/48	24/40	20/36
Japan	30	24	23	24/36	18/32	14/30
Low-Volume Vehicle:						
United States	36	32	28	24/48	22/40	18/36
Japan	28	24	20	20/36	16/30	12/28

STRATEGIC CONSIDERATIONS

There is consensus that an important competitive factor in the future will be the lead time from concept to production. At present there is some difficulty in making lead-time comparisons on an international basis, because the definition of when the process begins is not standardized. However, we have here attempted to develop only a broad measure of trends in this important factor. In general, both U.S. and Japanese manufacturers are expected to reduce lead time. The Japanese lead-time advantage, at present in the area of 3 years, is expected to diminish significantly by the year 2000. In fact, less than a 6-month advantage is envisioned for the Japanese at that point.

We segmented the question into two volume ranges: above 50,000 units and below 50,000 units. There appears to be some lead-time advantage based on the views of the panelists with low-volume vehicles. However, as noted in the comments, a number of panelists took issue with this idea. In any event, the low-volume vehicle advantage is less than six months.

Note that in earlier days of the industry, lead time was surprisingly short. For example, the 1955 Chevrolet was brought from concept to initial production in less than two years, and this was accomplished without the aid of computers. Of course, today's vehicles are more complex and regulatory aspects are far more severe. In the future, advanced computer technology and high-performance management should permit us to move back essentially to where we were over 30 years ago. It appears clear that we have sufficient basic technological capability but may not yet have the management focus or vision to execute products quickly. There is growing consensus that project teams with multidisciplinary membership and a strong leader together with a minimum of interference from top management is very helpful in streamlining the process. This is a crucial competitive issue for the industry and bears close watching in the years ahead.

Two additional considerations are important in reducing lead time: (1) comprehensive internal engineering data bases and an appropriate network to interface with them, and

(2) significant replacement of test and development with analytical tools (models, simulations, etc.). A true systems approach addressing every facet of the product development process is essential if the present system is to be brought to a world-class level. This means that real simultaneous engineering must be brought to bear on industry problems.

Another factor leading to reduction of lead time is the increasingly common practice of loading the shelf with validated technology and then when the clock begins on a given vehicle program, the technology is merely taken off the shelf and integrated into the program. This could be one of the key factors in future lead-time reduction. Too often North American manufacturers attempt invention during the product development process, leading almost inevitably to increased lead time.

TECH–6b. Please give your expectation *(in months)* of future development cycles from concept through Job One for a hypothetical new platform establishing new hardpoints.

Development	Vehicle Development Time *(months)*					
	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
High-Volume Vehicle (Production *more than* 50,000 units/year):						
United States	60	48	40	50/60	38/50	34/45
Japan	42	36	32	36/48	32/42	28/36
Low-Volume Vehicle (Production *less than* 50,000 units/year):						
United States	50	42	36	46/60	36/48	28/40
Japan	38	33	30	32/42	28/36	24/36

SELECTED EDITED COMMENTS

- Again, low-volume is not relevant.
- Component and concept development work will be done earlier, resulting in fewer product changes after Job One (start of volume production).
- If space-frame concepts materialize, idea of hard points changes dramatically.
- In the U.S. forecasts are essentially the same as TECH–6a. The critical path is seldom the "hard points." Body panels and instrument panel usually establish timing.
- Liability considerations will force longer development cycles for new vehicles introduced first in the U.S. than if they are introduced offshore.
- Low-volume vehicles require the same level of engineering, since hardpoint components like powertrains and chassis items are developed, at least partially, prior to the official start of a vehicle program.
- Newness of recall pressures will add to Japanese time frames.
- There will be a slow, gradual reduction from current levels; problems when too much pressure is put on for speed up.
- There are only a few platform types; everybody knows them all. The Japanese are still better at embellishing and coordinating a "vehicle type." Attention to detail, project integration throughout, and team approach at expense of individuality are reasons. Maybe that's why the upper scale Japanese cars come with "the works"—all the options are standard.

MANUFACTURER/SUPPLIER COMPARISON

As represented in the following table, the supplier panelists in most cases anticipate shorter development cycles than do the OEM panelists.

Development	Vehicle Development Time *(in months)*					
	Current Estimate		1995		2000	
	OEM	Supplier	OEM	Supplier	OEM	Supplier
High-Volume Vehicle:						
U.S.	60	54	48	46	40	38
Japan	44	40	36	36	33	30
Low-Volume Vehicle:						
U.S.	50	48	42	42	36	36
Japan	40	36	36	30	30	28

COMPARISON OF FORECASTS: MKT-20b

In contrast to the previous question, the Marketing and Technology panelists were in general agreement on the majority of the forecasts for the length of the development cycle for "new platforms establishing new hardpoints." The Marketing panel forecasts are shown in the following table.

Development	Marketing Panel Forecasts: Vehicle Development Time *(in months)*					
	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
High-Volume Vehicle:						
United States	60	48	40	49/60	40/50	36/45
Japan	40	36	30	36/48	30/40	24/36
Low-Volume Vehicle:						
United States	54	44	40	48/60	40/50	35/42
Japan	36	33	30	36/42	30/39	24/36

STRATEGIC CONSIDERATIONS

This question represented a slight variation of the prior one but addressed a more fundamental change, which includes redefinition of the vehicle platform, including the hard points. As expected, the lead times forecast are modestly longer than those for a major facelift. However, the differences are not of major significance. Both U.S. and Japanese manufacturers are expected to make considerable progress in the next ten years for both high- and low-volume vehicles. The analysis of this question is similar to the prior one.

Note that the lead-time advantage of the Japanese in the year 2000 is expected to be less than for a more modest facelift. A number of points made by the panelists in both of these questions should be reviewed carefully, because they suggest there are significant variations of opinion with regard to this issue. Considering the likely definitional problems of the panelists, the interquartile range is reasonably small.

TECH–7. What new technologies do you foresee could be utilized in spark-ignited engines to meet the proposed amendments to the Clean Air Act?

New Technologies	Percent of Panelists' Responses
Improved integrated and computerized adaptive engine controls	53%
New fuel injection controls, fuels	50
Improved catalyst systems, including new converters	30
Improved combustion efficiencies	15
Increased use of ceramics	12
New exhaust gas sensor technology	
No new technologies/present sufficient	8

Other technologies receiving 5% or less of total panelists' responses: alternate fuels, new EGR technology, lean-burn combustion technologies, reduced friction/high efficiency designs, multi-valve engines and other valve train technology, reduced accessory losses.

In order to provide as clear a representation as possible regarding the panelists' forecasts, *Representative Responses* are presented in lieu of comments.

REPRESENTATIVE RESPONSES

- Super fine spray fuel injection, air/fuel heating during cold starting, individual cylinder timing control, individual cylinder combustion control.
- Adaptive engine controls based on smart systems technology. Will use artificial intelligence (AI) theory/data for powertrain control.
- Adaptive engine/transmission controls based on direct readings of emittants (NOx, HC, CO).
- Better mixture control; more homogenous mixture; closer to exhaust port converter; leaner starts; better EGR/fast-burn chambers.
- Better engine heat management through design and materials innovation. Variable camshaft timing systems.
- Better closed-loop controls with drive-by-wire.
- Catalytic spark plugs; dilute combustion; improved injector atomization; alternate (oxygenated) fuels; sealed piston rings.
- Catalytically treated combustion chamber components.
- Ceramics to cut heat loss.
- Ceramics combustion chamber components, synthetic lubricants.
- Ceramic engine port liners.
- High-temperature engines, multi-stage super/turbo (composite) charging for high efficiency.

- Computer control of valve events: opening, closing, and lift. More precise closed-loop control of temperatures, air/fuel ratio, throttle dynamics, idle speed.
- Mass air-flow-based engine management systems (broader application of current technology).
- Feedback air fuel ratio control in richer and leaner air fuel (A/F) range. Fuel flexibility to enable methanol.
- Fuel quality (i.e., sulphur, reduced aromatics).
- Further refinement of electronic controls, catalyst, and O_2 sensor technology.
- Higher-temperature catalysts.
- Hydrogen and alcohol as fuels.
- Reduced oil consumption methods, improved oxygen sensors, vehicle mass and road load reductions, and closed-loop ignition timing.
- Lower friction, reducing parasitic loss.
- Better fuel atomization and distribution intake systems.
- Improved fuel metering during warm-up, acceleration, and deceleration.
- Increased use of sequential fuel injection, further enhancements in ignition systems, improved catalytic converters, using noble metal, etc.
- Sequential port injection.
- Low friction in all areas—bearings, lubricants, accessory drives, etc. Low-energy accessories, A/C compressors, generators, etc. using new magnetic and semiconductor technologies.
- Low-temperature catalysts. Hyper-lean mixtures. Individual cylinder/cycle optimization of ignition timing.
- Lower swept volumes, electronics for firing systems and fuel, camshafts.
- Performance calibration only on driver demand.
- Aluminum in place of cast iron, variable cam timing, more advanced electronic controls, variable induction systems, and ceramic components and surfaces.
- Multi-fuel capability with increased use of methanol blends. Sequential multi-point fuel injection using higher fuel pressures for improving atomization. Individual knock (cylinder pressure) sensors. Variable valve timing.
- Low-heat rejection designs.
- Refinement of three-way catalyst system. Greater use of sequential multi-point fuel injection. "Start-up" catalysts with bypass feature. Electronic EGR controls.
- Stratified charge.
- Those items that were investigated 10–15 years ago and only offered slight hydrocarbon (HC) reductions will be revisited to determine their HC viability based on 10–15 year improvement. No new technologies are foreseen.
- Turbine engine maybe. We are at diminishing return point for investment needed to further reduce emissions.
- Universal exhaust gas oxygen sensor. More refinement of present concepts.
- Use of ceramics to increase local combustion chamber surface operating temperatures—reduced "quench" effect for HC and reduced NOx.
- Valve timing control, intake manifold variable geometry, variable-speed auxiliaries, and exhaust heat energy recovery.

- Variable burn rate/intake swirl control. Low surface-to-volume ratio/low HC engine modifications. HEGO/VEGO sensor-based control. Adaptive control systems.
- Friction reduction. Non-camshaft-operated valves. Cooling systems allowing engines to operate at significantly higher temperatures. More precise ignition timing (spark initiation) as a result of electronics.
- More design optimization processes.
- Advanced sensors, especially pressure and temperature to control ignition with microprocessors.
- New technology per se not required. Further optimization is needed. Control strategies require development so that in-use compliance variation is reduced.
- Nothing revolutionary—just more electronic/adaptive control, more sequential port fuel injection, more catalyst, exhaust heat conservation.

STRATEGIC CONSIDERATIONS

Significant developments are forecast in spark-ignited engine technology to deal with expected amendments to the Clean Air Act requiring reduced emissions. While details of the emission requirements must be known before specific technologies are defined, the primary emphasis appears to center on control technology related to the internal engine processes, to the extent where events in each cylinder are optimized. A wide range of views are expressed and the reader is urged to review the *Representative Responses*.

In most cases, scientific breakthroughs are not needed; yet significant commercial issues remain in adapting present-day laboratory technology to cost-effective mass production. We suspect a major consideration will be the need for expanded durability. Many believe there will be a 100,000-mile durability requirement compared to today's 50,000 miles. Manufacturers may choose to accomplish this not only with improved integrity of the system but also by requiring a service overhaul or component update at some point in the life cycle of the product.

The new wave of engine up-teching must be watched closely because of the likely impact on other vehicle systems. With increasing customer demands for overall vehicle quality, it will be necessary for any new emission control strategy to offer good fuel economy and driveability performance as well as improved emission control.

Today's engines and those required for tomorrow are far more sophisticated than the relatively simple powerplant of just ten to fifteen years ago. Without continued electronic developments, improved materials, and better systems understanding, it will be very difficult to meet the challenges of the future.

TECH-8. With the increased technical complexity of post-1980 passenger vehicles, what do you foresee will be necessary on the part of both the OEMs and the dealerships/service centers to ensure "full life-cycle service" and a "satisfied customer?"

OEMs

Many of the panelists' suggestions for what they think will be necessary in order for the OEMs to be able to ensure "full life-cycle service" and a "satisfied customer" are somewhat nebulous and overlapping. For example, a reliable component would, a priori, be a quality component, and vice versa. In their responses, quality and durability are cited by a large number of the panelists and, therefore, an inherent part of their suggestions. Taking into consideration the preceding qualifier, the following table represents a quantification of the responses of the Technology panelists to this question.

Factors Necessary for "Life-Cycle Service" and a "Satisfied Customer"	Percent Total Responses
Improved and expanded on-board self-service capability*	44%
Increased reliability of systems and components	23
Improved serviceability	15
Extended liberal warranties	15
Increased training for dealers and service personnel	11

*Many panelists within this category specified *artificial intelligence (AI) systems* for use by dealerships.

NOTE: The following suggestions received less than 10% of the total panelists' responses: increase in modular servicing; more simplified systems and improved vehicle design; a more positive OEM interaction with dealers.

REPRESENTATIVE RESPONSES

- Adequate technical service must be available for dealers. Will the OEM support the independent market?
- There must be design of vehicle systems to allow cost-effective and widespread use of modular replacement of key components and systems to allow dealers to provide one-day repair service.
- Economical "black box" replacements versus repair of malfunctioning part. Proven quality, long-life components.
- Fail-safe electronic systems with get-home capability. Keep electronic systems divided enough to keep module replacement costs reasonable. Cartridge-type oil change.
- Fewer vehicle problems which require low-mileage return trips for service. Longer intervals between service.
- Greater degree of control and support of the dealers, including part ownership of dealers by the OEMs.
- Increased involvement at customer service level and on-line data from the field.

- Increased emphasis on dealership training, maybe to the extent of a quality-type audit system by the OEMs.
- Ensure a quality product at all levels. The small defects seen at the dealer level ties up the mechanic and places the customer on a waiting list for repairs.
- Integral diagnostics tending toward prognostics. Greater on-board storage of intermittent conditions.
- Integration of voice of customer, QFD, Taguchi techniques, and systems engineering with statistical process control at shop-floor level.
- Interactive dealer diagnostics, widely available readout equipment, hotlines, liberal warranty policies.
- Repair kits for ten-year-old cars covering everything from electronics to mechanical controls.
- Protection against fake parts.
- Make new systems as simple as possible for mechanic understanding. Install systems where they can be readily worked on inside vehicle.
- Mechanic certification training emphasized.
- Development of on-line artificial intelligence diagnostic systems for dealer use.
- More positive interaction with dealers, especially service organization. OEMs need programs to get suppliers moving in direction of quality and service.
- Must provide the capability in the complex systems for diagnosing problems and allowing quick and accurate repair or replacement.
- More understandable instruction for consumers regarding maintenance.
- Quality: components can't fail; if they do, we all fail.
- Reliability of electronic systems, extended warranties on same, education regarding what and why of new system advantages, etc.
- Reliable procedures and direction on corrective action. Fast response to special situation items.
- Rigorous development, finite material element analysis (FMEA) and reliability analysis, quality control, and sophisticated diagnostics.
- Slow down electronic junk. Simplify the vehicle. Concentrate on cost effectiveness and quality of design instead of just high-tech appeal imagery.
- Some effective way to currently diagnose and correct intermittent malfunctions, without dealerships guessing "replace a sensor" and then waiting to see if customer complains again.
- Supply computer-based data acquisition and "rapid" diagnostics hardware and software; integrated technician system.
- Vehicle self-diagnostics and diagnostic efficiency must be designed in all components. Service support and mechanic efficiency must be given greater emphasis.
- Very high reliability over extended life of vehicle: 150,000 miles.
- OEMs will have to disseminate information quicker than they do now and that information will have to be more complete. They have to do a better job with service manuals.
- Trend will be to service powertrains at higher system level rather than individual components. System would then go to a center for repair/rebuild, using processes equivalent to production.

DEALERSHIPS/SERVICE CENTERS

Factors Necessary for "Life-Cycle Service" and a "Satisfied Customer"	Percent Total Responses
Better trained service personnel/Fix right first time	52%
Increased computerized diagnostic/service capability with an integrated data base interface with the OEM	49

Other suggestions receiving a significant response are as follows: improved customer interaction and relations concentrating primarily on customer-oriented service and satisfaction; faster service turnaround with emphasis on one-day repair for most problems; ability to recycle modules; higher pay for trained automotive technicians.

REPRESENTATIVE RESPONSES

- Ability to re-program on-vehicle devices.
- Better diagnostics at the service bay. Much improved "fix-it-the-first-time" capability.
- Computer network involving integrated business and technical systems with overnight upload/download to manufacturer.
- Dealers will have to use the OEM supplier information and train and retain their service technicians.
- Direct on-line electronic communications/diagnosis with dealers.
- Domestic dealers must change their attitude in dealing with unhappy customers.
- Extended warranty coverage; "customer-focused" service practices.
- Fewer dealerships, more qualified personnel.
- Get the car back to the customer when promised. Ongoing training of mechanics is a must. Demand quality products be used on all repairs.
- Good diagnostics. Fast and reliable service procedures and good communication to customer on corrective action.
- Have necessary equipment available for servicing the high-tech parts. Provide mechanics with training required to understand new systems.
- More concerns over customer impressions while at the dealerships.
- Improve service—open nights and weekends.
- Increased use of regional dealership service centers.
- Increased service value relative to the vehicle's cost. Cost should not increase with the cost of the car.
- Investment in systematic trouble-shooting procedures and diagnostic equipment and employee training. Real time communication tie back to the OEMs knowledge bank. Sales person's training in the product. Shorter service turnaround time to fix vehicle.
- Loaner cars, no customer inconvenience; home pickup and delivery.

- More training for mechanics and acceptance of lower percentage of "back room" profits to total dealership profits.
- More training—specialization in specific areas. More sharing of expertise between dealers. Will be less maintenance but more specialized requirements.
- More training, enforcement of "use the diagnostics." Purchase of computer diagnostic equipment which ties to OEM.
- Inability of independents to stay up with dealerships will dictate service takes place at dealership.
- Relearn the meaning of the word "service." Some on-the-job training at dealerships and service stations in Japan would help.
- Require more diagnostic equipment and training "mechanics." Customers don't trust a kid who just changes circuit boards—it's like the old vacuum-tube testers they had at the 7–11 stores.

STRATEGIC CONSIDERATIONS

The increasing complexity of the standard passenger car is an important factor in the all-important interrelationship between the OEMs, dealerships, and customer. This is reflected in service operations and customer-perceived quality and reliability. The goal must be total customer satisfaction.

The rapid pace of electronics use has presented some problems with system reliability and repairability. However, the maturing of automotive electronics technologies has greatly improved reliability. The expansion of improved on-board and off-board diagnostic capabilities should improve diagnosis and repair of electronic and some mechanical systems.

A very critical issue in true "life-cycle service" is the aftermarket. Presently, nearly 75% of the vehicles are serviced independent of the franchised dealer system. Manufacturers must find ways to improve the quality of all service channels if they hope to retain customers' loyalty. This challenge is particularly crucial as modern vehicles with increasingly sophisticated electronics enter the aftermarket for service. The manufacturers must provide assistance to these independent service channels. However, this will almost certainly cause serious conflicts with traditional dealers. This is a classic dilemma requiring both creativity and the wisdom of Solomon.

TECH-9. What do you foresee will become major new opportunities for aftermarket sales and service industries (excluding do-it-yourself) in the 1990s?

Major Opportunities for Aftermarket Sales and Service	Percent Total Panelists' Responses*
Establishment of electronics-only module repair, remanufacture, and replacement centers	31%
Expanded electrical/mechanical diagnostic and repair centers	17
Entertainment systems installation	15
Production of low-cost, at-home diagnostic equipment and tools including computers	15
Electronic add-ons for enhancement/customization	13
Material body appearance modifications/ enhancements for styling/customization	8
Service contracts	4
Extended use of car phones	4
Increased specialization	4
Reduction in aftermarket service opportunities	4
Software upgrading	3
Establishment of independent aftermarket foreign-car parts centers	3

*NOTE: Total response adds to over 100% because of some overlap in categories.

REPRESENTATIVE RESPONSES

- Dealers, through trained mechanics and leading edge technological equipment, should increase share of maintenance.
- "Lifetime" maintenance. Full vehicle warranties. Guaranteed customer satisfaction. "HMO" car-care plans.
- Appearance modifications. Car phones. Repair/replace airbags. AAA-type trip guides or tracking system with visual displays based on map cartridge or digital disk/laser disks.
- Development of training schools for electronics technicians and high-tech diagnostic shops for repair.
- Electronics-only repair. Item-only service (oil change, tune up, suspension, etc.).
- Electronic diagnostic equipment—both stand-alone and in connection with the on-board diagnostic modules.
- Electronic enhancements as vehicle systems become more modularized and standardized, like hi-fi and computer hardware.

- Expanded lines of foreign componentry for foreign vehicles. Electronic defeat systems and replacement parts. At home analysis—diagnosis instruments—mistrust of dealer analysis. Fast oil change plus minor integration.
- Expanded services offered by tune-up shops, particularly electrical system diagnosis. Entertainment system installation.
- Electronic fuel injector (EFI) components (injectors/pressure regulators). However, dealerships, if wired into diagnostic service capability of OEMs, will make independent aftermarket growth difficult.
- Good diagnostic centers with an adequate service supply line that "fixes" instead of "excuses" problems. Preventative maintenance expansion: plugs, electronic modules, other "wear" items.
- Independent aftermarket parts for imports.
- Low-cost electronic device in conjunction with more widely available diagnostics of, expanded to mass-marketing (Sears, K-Mart, Speedy Tune, etc.).
- Modular construction will challenge traditional part-for-part replacement. Rebuilding of modules will be increasing trend.
- Most growth in basic services: (1) replacement of tires, muffler, battery, shock absorbers, etc.; (2) oil change and lube (reduced service for dealers); (3) collision repair and service (reduced service for dealers).
- Reclaim and reprocess of refrigerants.
- Reconditioning shops capable of doing anything necessary to make your 50- or 100,000-mile car like new (electronic, body, engine, transmission, brakes, etc.).
- Reduction in sales of vehicle spare parts/service through "non-affiliated" stores.
- Serial data bus "add ons" that perform some aftermarket function but don't require adding wires to the car.
- Service will take a nose dive. Cars will not require service.
- Small franchise—shopping mall car dealerships. High-performance, electronic add-ons—EEPROMs.
- Smart laser disc-based diagnostic systems.
- Specialists will control the aftermarket. Rebuilders will flourish.
- These guys are in trouble—they either spring for the high and diagnostic equipment (if available), or they can do tires, shocks, exhaust, and "minor body work." More and more are modular, go/no-go black boxes which can't be repaired or tuned.
- If OEMs drop the ball, third-party development of sophisticated diagnostic systems.

STRATEGIC CONSIDERATIONS

The entire service issue is extraordinarily complex. It is a particularly important area in light of increased demands by the customer for quality in every aspect of his or her experience with the automobile. In fact, as we move into the decade of the nineties, it is clear that many of those factors that have served as differentiators between products, such as fit and finish quality, crashworthiness, corrosion protection, reliability, etc., will cease to be differentiators as most of the world's vehicle manufacturers essentially achieve world-class standards in these quality or value items. With increased parity in key, traditionally competitive areas, even more emphasis will be placed on the total service experience as a factor necessary to achieve true world-class customer satisfaction.

From an overall standpoint we envision there will be reduced opportunities in the aftermarket because of improved component and system durability and a continued movement to extended maintenance intervals. A significant conflict will undoubtedly emerge between the aftermarket and franchised dealer system, particularly as higher-tech products begin to enter a period of product life necessitating service and/or repair. A higher level of automotive manufacturer input will be required to provide this appropriate service.

As the total aftermarket shrinks, there will undoubtedly be a redistribution of the remaining business. While there will be some significant winners and some significant losers, one thing is clear: any group that expects to be strongly positioned in the aftermarket must have the sophisticated technical capability to deal with state-of-the-art automotive electrical and mechanical systems. This is a challenging area requiring creative and innovative thinking by the industry in the years ahead.

TECH-10. New vehicle warranties appear to possess the ability to differentiate future vehicle offerings. In the various areas listed below, what are your *opinions* (please consider various vehicle segments) concerning the major considerations, variations offered, and level of duration (time and/or miles) for future warranties in the following areas?

ENGINE/TRANSMISSION/TRANSAXLE

Length of Warranty	Percent of Responses
8–10 Years/100,000 Miles	51%
5 Years/50,000 Miles	11
6–7 Years/100,000 Miles	7
7 Years/70,000 Miles	7
No Change	7
Lifetime	6
3 Years/36,000 Miles	2
Other	9

REPRESENTATIVE RESPONSES

- "5 and 50" with no deductible will be price of entry.
- Big gains in quality, reliability, and dependability will be made: 6 years/60,000 miles.
- Cars: 125,000 all components. Trucks: 200,000 all components.
- Competitive warranty offerings. Other enhanced service programs.
- Covered in bumper-to-bumper package but will extend to 10 years and 100,000 miles or more depending upon manufacturer.
- Current coverage will be reduced—like GM did with "bumper-to-bumper"—maybe back to 3 years/30,000 miles.
- Current warranties may not change much.
- Customers will expect these systems to perform flawlessly for 100,000 miles. This will become a common expectation among all market segments.
- Further demand for improved quality and reliability will push warranty for powertrain components to a higher mileage level. Ten-year/100,000-mile protection likely by 2000.
- Future warranties will run 10 years/100,000 miles. For the most part, this is a marketing ploy. Most car buyers trade long before this limit. A quality-built car should meet these limits now!
- Moving to 10 years/100,000 miles for powertrain and emission controls—$100 deductible.
- New vehicle warranties demonstrate increased confidence by the manufacturer in quality and reliability. Powertrain warranties provide customer piece of mind.
- Heavy-duty vehicle manufacturers already have extensive warranties. Passenger vehicles and light-duty vehicles may go to longer warranties but there may be maintenance or abuse restrictions applied.

- Powertrain warranties will be significantly reduced due to aggressive evaluation of components by manufacturers and suppliers. More worker participation in manufacturing process.
- Price of vehicles increasing faster than consumer's ability to pay. Consumer will keep vehicles longer. Increasing warranties of 75,000/100,000 miles will appeal to low- and medium-income families.
- Simple, understandable, all-inclusive warranties with reasonable deductible after first year ($100). Customer confusion generates ill will.
- Some "zero cost of ownership." 100,000-mile warranties will require (include) oil/filters.
- Ten-year/100,000-mile warranty with deductibles kicking in after some stated mileage on all but least expensive vehicles.
- Ten year/100,000 miles is the target. Seals and oil are concerns. Also collision damage and improper service. Electronic memory of diagnostic actions may provide trail.
- Five years/50,000 miles will be the standard of the industry. Manufacturers are likely to offer second-owner warranties.
- Five years/50,000 miles in the near future, but the company that can offer a 100,000 full warranty will lead the industry.

COMPARISON OF FORECASTS: MKT-19

With respect to length of warranties for engine/transmission/transaxle, a greater number of Technology panelists expect longer warranty periods than do Marketing panelists. While a larger number of Marketing panelists expect lifetime warranties, the combined range of 6 to 10 years/70,000 to 100,000 miles received a significantly greater response from the Technology group.

Engine/Transmission/Transaxle: Length of Warranty	Marketing Panel	Technology Panel
Lifetime	12%	6%
8–10 Years/100,000 Miles	32	51
6–7 Years/100,000 Miles	12	7
7 Years/70,000 Miles	0	7
5 Years/50,000 Miles	32	11
3 Years/36,000 Miles	12	2
No Change	0	7

NON-POWERTRAIN ITEMS
i.e., Body, Electrical, Comfort/Convenience

Length of Warranty	Percent of Responses
10 Years/100,000 or more Miles	30%
2 Years/25,000 or more Miles	20
3 Years/36,000 Miles	16
5 Years/50,000 Miles	11
No Changes/Not Important	11
1 Year/12,000 Miles	5
Bumper to Bumper	5
Lifetime	2

REPRESENTATIVE RESPONSES

- Bumper-to-Bumper warranties offer additional confidence and promote reliability and quality of products. These packages may extend to 5 years and 50,000 miles.
- There will be competitive warranty offerings and other enhanced service programs with state-of-the-art technology application.
- Functional features will be more like powertrain. Visuals won't be warranted beyond 12 months/12,000 miles.
- No major changes expected. Comparable vehicles must meet what the leader offers in warranties.
- Non-powertrain coverage will increase to 3 year, 30,000 miles (first-owner coverage).
- Non-powertrain warranties, excluding body electrical, will remain consistent with current levels; body electrical problems should be reduced due to improved manufacturing expertise.
- Subcompact/compact: 12 months/12,000 miles. Mid-market/mid-size: 5 years/50,000 miles. Large/Luxury: first owner lifetime/100,000 miles.
- This will become a discriminator and become more competitive in cars and trucks with bumper to bumper.
- Upper-level buyers will expect everything to be covered for as long as they own a vehicle. In lower segments, buyers will trade off cost and warranty.
- Warranties on these items may have to be extended (at a cost) as more electronic items are added to cars to avert customer rejection. The Japanese are almost certain to lead in this area.
- This type of warranty will not be important in low- or medium-price cars/trucks. Luxury cars may offer this, particularly the specialty-type (Corvette, etc.).

COMPARISON OF FORECASTS: MKT-19

A significant consideration in the comparison of technology and marketing responses with respect to warranties on non-powertrain items is the percent of Technology panelists that consider this feature not important or expect no change.

Non-Powertrain Items: Length of Warranty	Marketing Panel	Technology Panel
More than 3 years/36,000 Miles	40%	48%
3 Years/36,000 Miles	40	16
Less than 3 Years/36,000 Miles	20	20
No Change/Not Important	0	11

MAINTENANCE ITEMS

A significant number of the panelists responded with rather general statements regarding maintenance warranties. The percentages presented in the table represent those comments that were considered quantifiable. The remaining opinions are in the *Representative Responses*.

Length of Warranty	Percent of Responses
No Change from Current Practice	38%
3 Years/36,000 or more Miles	23
2 Years/24,000 or more Miles	13
1 Year/12,000 or less Miles	13
Increased availability of service contracts	13

REPRESENTATIVE RESPONSES

- This area will be available only with maintenance contracts and included with some ultra-luxury cars.
- There will be competitive warranty offerings with enhanced service plans and packages.
- These items will continue to be covered by owner. Oil change intervals will be reduced to about 5,000 miles.
- Could be some increase in all sectors. There are a few outside influences that are hard to control, i.e., road condition, driving habits, load, etc.
- I expect a number of companies will include many of these items in warranty. Customer will only have to add air to tires and gas to tank.
- I expect some limited coverage to ensure that major problems don't develop later.
- Front-end accessory drive belts: 30,000 miles. Oil changes: 5,000 miles. Spark plugs: 60,000 miles.
- This is a function of product marketing.

- Improved materials should reduce normal wear and tear. Brakes, tires, windshield wiper blades will last longer in the future.
- Limited coverage in bumper-to-bumper packages probably 3 year/36,000 miles. Some "normal wear components" will require a blanket cost.
- Limited use—might be used to keep service at dealers as reliability improvements take work out of dealerships.
- This item will not be covered except some specialty cars and option packages.
- Number of maintenance items will continue to decrease. Most companies will not offer warranty.
- OEMs will offer customer an optional maintenance agreement based on miles driven—up to ten years.
- Similar policy to today, with extended mileage.
- Expect some increase in normal maintenance coverage as manufacturers look for competitive edge. Ten percent of all vehicles by 1995, 40% by 2000.
- Subcompact/compact: 12 months/12,000 miles. Mid-market/mid-size: 5 years/50,000 miles, no cost. Large/luxury: first owner, no cost.
- This area will continue to be excluded. Efforts are being made to reduce the number of these items.
- This is the next step after bumper-to-bumper. It will be avoided as long as possible.
- This would only add to vehicle cost. Customers expect normal maintenance.
- Up-scale customers will expect dealers/manufacturers to cover all normal maintenance. In lower segments, buyers will expect extended maintenance intervals.
- OEMs will see service contracts as appliance manufacturers do.

COMPARISON OF FORECASTS: MKT-19

It appears that once again the Technology panelists expect longer warranty periods for maintenance items.

Maintenance Items: Length of Warranty	Marketing Panel	Technology Panel
No change from current practice	32%	38%
Over 1 Year/More than 12,000 Miles	36	46
1 Year/12,000 or Less Miles	32	13
Increased availability of service contracts (unspecified duration)	0	13

CUSTOMER SERVICE
i.e., road service, resale value, etc.

Variations Offered	Percent of Responses
Dealer-sponsored road service	25%
No guaranteed resale value	16
Guaranteed resale value	13
Increased availability of service contracts	13
Other (see *Representative Responses* below)	33

REPRESENTATIVE RESPONSES

- Only on specialty cars. Some brands may pursue but will be limited application.
- Allante/Cadillac/Daimler Benz have the proper idea.
- As cars get more expensive there may be a larger market for previously owned newer cars. Life expectancy on vehicle population has increased and probably will continue.
- Assuming current rate of inflation and the value of the dollar, with improved warranties, resale value will remain consistent with current levels. Due to rising costs more vehicles will be leased.
- Due to current product reliability (or lack of), expect this type of coverage on foreign vehicles with minimal trials by domestics to establish package cost or to be competitive from a marketing standpoint.
- Expect expanded service hours; loaner cars, pick-up, and delivery. Maintenance contracts.
- Expensive autos may be expected to come with guaranteed resale value.
- Higher-priced cars will offer road service (free towing).
- In transmissions, diagnostics can provide increased information on condition of clutch pack, etc.
- New entry, top-of-line vehicles may require resale guarantee to be accepted.
- No guaranteed resale factor, but will go to dealer/factory-sponsored road service in the future.
- No guaranteed resale programs will emerge. The few companies who do will either lose big (poor quality, reliability, and durability—QRD) or find no advantage (parity in QRD).
- No strong marketing advantage for this offering.
- Resale value of 5-year-old cars will increase as long-term (100,000-mile) durability improves.
- Road service: 12 months/12,000 miles. Resale: none.
- Road service will be included and resale value will be guaranteed.
- Road service, 3 years. No resale value.
- Sporadic marketing gimmicks, although guaranteed trade-in value may catch on.
- Subcompact/compact: no change. Mid-market/mid-size: road service included in 5-year/ 50,000-mile warranty. Large/luxury: road service.
- Total car care such as Chrysler's "Crystal Key" plan on their premium cars will become commonplace.

- Up-level customers will expect this service to be covered by dealers/manufacturers. In lower segments, buyers will expect improved coverage (i.e., all roadside service, loan vehicle, etc.).
- This concept will diminish in important due to higher mileage warranties.

CORROSION

Length of Warranty	Percent of Responses
10 Years and/or 100,000 Miles	43.0%
5–7 Years/50,000–70,000 Miles	36.0
Lifetime	7.5
No Change/Current Warranties	7.5
Other Generally Stated Improvements	6.0

REPRESENTATIVE RESPONSES

- All buyers will expect 100% warranty on corrosion.
- All vehicle components are receiving increased attention on appearance.
- Appearance: 5 years/50,000 miles. Rust-through: 8 years/100,000 miles.
- Cars: Corrosion-free for 125,000 miles. Trucks: Corrosion-free for 200,000 miles.
- Expect 10-year perforation and 5-year cosmetic to become standard but limited by mileage. Also expect exclusion clauses to remain, such as Chrysler's outer panel perforation restriction.
- This has become a non-issue.
- Improved corrosion resistance due to more extensive use of coated steel, use of composites, and alternate materials (zinc, aluminum).
- Improved materials (plastics, etc.). Improved paints and protective coatings. Construction and fastening system details.
- Many corrosion problems of the past are corrected. Finishes and coatings will probably be improved, allowing already generous warranties to be extended.
- Most cars, 5 years/50,000 miles. Luxury cars, 10 years/100,000 miles.
- Should be 10 years or 100,000 miles.
- This feature will appeal to low- and medium-price car buyers.
- Industry will eventually go to 10-year rust-through 5–7 year cosmetic-rust-damage warranties on all cars.

COMPARISON OF FORECASTS: MKT-19

A review of the following table indicates that a reasonably good consensus exists between the two groups of panelists.

Corrosion: Length of Warranty	Marketing Panel	Technology Panel
Lifetime	9%	7.5%
Over 7 Years/Over 70,000 Miles	46	43.0
5–7 Years/50,000–70,000 Miles	37	36.0
No Change/Current Warranties	8	7.5
Other: Unspecified Warranty Improvements	0	6.0

OTHER: GENERAL RESPONSES

- As warranties become longer, the cost of the parts and vehicle go up due to increased material and design costs. As the cost increases, the vehicle has to last longer for the market to afford to pay for it through longer financing. This again brings pressure for longer warranties.
- Everything is moving toward total coverage for longer and longer times.
- In general, the trend will be for lifetime coverage except for obvious wear items such as tires.
- Loaner cars will be provided and all added repairs will be covered.
- Longer warranties equal more profit for dealers.
- The net effect of new warranty features will significantly affect the "do-it-yourself" mechanics. More sophisticated powertrains and electric/electronic components will make it impossible to repair a vehicle yourself.
- This concept will force better control of dealer activities in order to control cost.
- Warranty on emission control components is likely to be extended, especially if 100,000-mile compliance regulation is adopted.
- The industry must make major improvements in this area.
- Present durations and coverages will not change drastically by the year 2000.
- Warranty will be a non-issue as quality/reliability improves and manufacturers are at parity.

STRATEGIC CONSIDERATIONS

As is evident from trends of the past few years, it is clear the automotive manufacturers are attempting to use warranties as a product differentiator and as a means to convince the public that the quality of their product has improved dramatically. This multi-faceted question considers powertrain, non-powertrain, maintenance, corrosion, and service areas. There is a general consensus that compared to today the industry will move to higher levels of warranties. This is particularly true with the upper-scale or luxury-type vehicles. There is also a strong suggestion within the responses that the industry's capability is improving to such an extent that proposed warranty improvements may not necessarily create excessive hardship.

Other issues will be important with respect to this issue, e.g., the possibility of the federal government requiring a 100,000-mile useful life for emission control systems rather than the present 50,000 miles. This will undoubtedly raise some very challenging concerns in that improper service or maintenance, or the use of inferior materials such as a poor lubricating oil, become an increasing problem as vehicles age but still may be within the warranty period. We suspect this will lead to far more rigorous standards on everything from service to various materials including fuels and lubricants. An additional result will undoubtedly be a more capable diagnostic system that will assure appropriate service before a major problem develops. This should also assure that, if or when a problem does occur, that problem is fixed right the first time.

Above all it must be noted that present-day and future customers are, and will be, more demanding of quality in all commercial products, especially their personal vehicles. With growing overcapacity, the vehicle manufacturers will be pressed to truly provide total customer satisfaction. Anything less could lead to failure in the marketplace. Creative warranties would seem to be a natural avenue to at least partially address this matter.

TECH-11. It is clear that solid waste and material recycling/environmental issues will become far more important in the upcoming decade. It is also becoming apparent that light-duty vehicle design will undoubtedly be impacted by these issues. Please indicate ways in which you think the automotive industry, both OEMs and suppliers, will or should respond in the design, production, and ultimate retirement of future vehicles.

Recycling Strategies	Percent of Panelists' Responses
Need to develop recyclable/biodegradable materials	46%*
Need for OEMs to devise "buy back" and reclamation programs	19
Need for both OEMs and suppliers to consider recyclability/reclamation in vehicle design process	19
Enforcement of recyclability	16

*Within this group, 25% specified the need to avoid the use of nonrecyclable materials; 17% the need to develop processes for the separation and reclamation of salvagable/recyclable materials.

REPRESENTATIVE RESPONSES

- Need active plan to recycle plastics. If OEMs and suppliers don't get started, government will dictate. Government won't know as much as the OEMs and therefore will enact dumb laws.
- All materials utilized in the vehicles need to be 100% recyclable and utilized for future production, thereby reducing the waste problem.
- Automotive manufacturers should become involved in the total vehicle cycle: build vehicles, maintain and service vehicles, buy back and recycle.
- Avoid use of composites that will not burn without harmful effluents. Begin use of recycled materials where possible. Design for use of chlorine-free refrigerants (R-134a). Lubricant development is needed; this is a serious concern.
- Avoidance of materials which become toxic under recycle conditions. Cost of materials may shift significantly depending upon cost of recycle energy required.
- By 2000 would expect virtually complete use of either recyclable or biodegradable materials. Also expect legislation to force this, as well as deproliferation of plastics into a "few" recyclable families.
- Companies must put consideration into the design process. Government regulation is coming! Industry should anticipate and provide guidance to government.
- Design must consider the use of both recyclable materials and environmental safe disposables.
- Don't see a trend; increased materials mix will make matters even worse (more difficult to recycle). Longer-lived vehicles means either a smaller total market, or export used

vehicles to Third World countries (if customers continue to replace good cars with new ones based on fashion/technology).

- There is a need for the easy removal of non-ferrous components for recycling of ferrous metals.
- Forward model planners and scientific lab types need to address these issues to first develop a set of guidelines or recommendations that the production engineering group can use in engineering release decisions.
- Freon and other harmful chemicals will be removed from abandoned cars, probably paid for by a tax at time of purchase.
- If recycling gets far enough along we may have to design vehicles that are easily disassembled and segregated by materials.
- Ensure that the materials used are recyclable and are not cancer-causing agents. This can be accomplished by improved cooperation between OEMs, suppliers, and government agencies.
- It is felt that this requirement will not drive the design of the vehicle, but improved methods of processing the retired vehicle will be developed. Legislation on certain materials or subassemblies that may be harmful to life or environment will probably be made as a result.
- There will be a move to lease vehicles to customers or buy back for recycling.
- Need retirement by materials classification. Separate those materials that can be reused for parts and that are going to land fill or have fuel value.
- New manufacturing processes are required by OEMs. Components influence materials choices and design.
- One solution that seems to work in packaging is the "deposit system." It is conceivable that a government mandate could require a cradle-to-grave deposit on the vehicle—possibly prorated to vehicle weight to allow (and encourage) part reclamation before total retirement.
- OEMs and plastic suppliers should enter into an R&D consortium (jointly financed) to develop methods of recycling mixed/painted plastic scrap from retired vehicles. No practical, cost-effective technology is available today which can produce parts with any significant value. GE's ABX program is more public relations than real and only deals with a very small portion of the scrap as currently structured.
- Develop program to pay for vehicle disposal during life of vehicle.
- Reclamation of composites (graphite fibers cause problems in the environment). Total energy balance—cradle to grave—manufacturing operation, reclamation. Increased use of rebuilt components in service (parts exchange programs to help reduce service costs).
- Return and recycle through manufacturer's representatives (e.g., GM takes back all GM vehicles to recycle/recover materials). Sub-agreements send specifics back to suppliers (e.g., tires, glass).
- Should form cooperative task force with recycling industry, vehicle OEMs, and suppliers/ government to identify issues and materials of concern and plans (or legislation) to deal with them before we grow into an avoidable crisis.
- Should look at biodegradable plastics. Recycling technology becomes important in material strength, etc.
- The plastics industry needs to develop more environmentally sound production techniques and toxic waste-handling capabilities. Recycling of plastics is also crucial.
- They (OEMs and suppliers) will only talk, gripe, complain. They should stick to highly recyclable materials such as steel.

- OEMs and suppliers won't respond. Recyclers (junk yards) must revolutionize their way of doing business.
- Vehicles should be totally recycled into reusable material. Components will require a greater degree of breakdown.
- We now consider the problem of recycling in our design process since at least 1960. We want to use materials that can be recycled for our own benefit in our own plants.
- Industry will develop efficient ways to recycle plastics, copper, stainless steel, and precious metals.
- Auto industry will work with government to establish a plan.

STRATEGIC CONSIDERATIONS

There is no question that the total interface between light-duty vehicles and the environment is becoming an increasingly important issue. For some time the industry has faced problems associated with emissions and safety, but now additional factors are emerging. Recycling is one of these issues. It brings an important new challenge to automotive designers and suppliers. We envision that in the next few years most of the manufacturers will begin to develop essentially life-cycle management concepts related to their product, i.e., they will manage the product not just out-the-door and through the warranty period within their own dealer organization, but all the way through its life cycle and, in effect, into the back door of a recycling plant. The responses throughout this question should be read very carefully, because a wide range of views are expressed that need to be considered. Whereas some feel the entire issue is well under control, there are others voicing significant concerns, particularly with regard to plastics and freon. We believe this is a major issue and will become a significant factor in automotive design in the future. In fact, we believe important business opportunities will emerge for both the manufacturers and suppliers with regard to the overall recycling issue. Failure to consider some of the important system-based aspects of this issue could be an important competitive issue in the next decade. We believe both manufacturers and suppliers should become proactive in their approach to this matter.

TECH-12. In your opinion, what percent of total sales revenue should manufacturers and suppliers typically apply to (1) capital investment and (2) research and development *and* what percent do you feel these manufacturers and suppliers actually do apply to capital investment and R&D?

Application of Total Sales Revenue to:	Median Response		Interquartile Range	
	OEM	Supplier	OEM	Supplier
Capital Investment				
Percent Should	10.0%	10%	7/15%	6/15%
Percent Actual	7.0	5	5/10	4/10
R&D Expenditure				
Percent Should	6.0	5	5/9	4/10
Percent Actual	3.5	3	3/5	2/5

SELECTED EDITED COMMENTS

- Capital investment is, to a very large extent, a function of existing financial structure and health of the company along with overall business climate. R&D expenditures are difficult to clearly identify and are typically overstated. For domestic OEMs current rates are not adequate to remain competitive.
- Capital investment requirement varies with age of plant, new technology, and sales/ capacity situation for each supplier. There is no "should" number.
- Capital spending and R&D should depend on specific business; the above figures are "average."
- Definition of R&D by auto industry is based more on tax consideration than on actual technology investigation.
- Assume R&D means "real R&D" and not currently accounted product-development costs.
- Actual numbers are too low!
- Percentage for "supplier" varies significantly by product category and maturity level of similar products.
- This must be adjusted periodically, depending on profits, the economy, market share, etc.
- With increased outsourcing, suppliers are going to have to make proportionately greater investments in plant and equipment and R&D to get and keep their business.

MANUFACTURER/SUPPLIER COMPARISON

The only difference of opinion between the manufacturer and supplier panelists with regard to this question is with the percent of total sales revenue that the OEMs *actually* do apply to capital investment. The opinion expressed by the supplier panelists was 5%, whereas the consensus opinion of the OEM panelists was 10%.

TREND FROM PREVIOUS DELPHI SURVEYS

In Delphi III the following question was asked: "What percentage of total sales revenue should a prudent automotive manufacturer or supplier apply to capital investment and R&D under normal conditions over the long run? Relevant data resulting from this question is presented in the following table.

Application of Total Sales Revenue to:	Recommended Capital Investment and R&D Percent of Sales for: Manufacturer	Supplier
Capital Investment: Median Response	10%	10%
R&D Expenditure: Median Response	5	5

STRATEGIC CONSIDERATIONS

Both the manufacturers and supplier panelists responding to this question believe a greater level of their resources should be devoted to both capital investment and R&D. In fact, they believe these investments should be nearly twice their suggested actual levels. This implies that we could see an expansion of investment in both areas in the years ahead. All industry participants will be dealing with far more complex and sophisticated technical problems which will place a greater premium on technology as a product differentiator. In addition, the increasing emphasis on reducing lead time and frequent model changes could further accelerate both capital investment and R&D expenditures. In fact, the level of R&D spending in the automotive industry stands in rather stark contrast to basic industry sectors that traditionally have devoted a far more significant level of sales dollars to research on new technology. A critical question confronting the automotive industry is whether there is sufficient human and other resources available to meet this challenge.

As stated in *Selected Edited Comments*, significant differences may be expected of suppliers because of great variations in product, technology, competition, etc. Clearly, it is dangerous to generalize with regard to such a diverse group. In any event, competitive pressures will probably dictate some expansion in spending, particularly R&D.

II. BODY/CHASSIS: MATERIALS, SUSPENSIONS, BRAKES, TIRES, INTERIOR FEATURES AND SAFETY

TECH–13. For each of the following factors, check the degree of influence you believe each will have on future light-duty vehicle design in the next ten years.

Factors	Degree of Influence		
	High	Medium	Low
Quality	90%	9%	1%
Foreign Competition	73	26	1
Market Demand	72	27	1
Styling	71	28	1
Durability	67	31	2
Manufacturing Cost (non-labor)	62	33	5
Performance	55	44	1
Integrated Vehicle Systems	43	46	11
Improved Engineering/Development Process	55	35	10
Higher Tech Powertrain	42	47	11
More Efficient Powertrain	42	53	5
Comfort	40	56	4
Safety	35	59	6
Labor Cost	34	53	13
Fuel Economy	26	61	13
Weight	20	68	12
Aerodynamics	19	68	13
Sourcing Considerations	17	56	27
Self-Diagnosis	16	58	26
New Computer Architecture Concept	16	55	29
Development & Availability of New Materials	16	64	20
New Software (e.g., artificial intelligence)	12	50	38

SELECTED EDITED COMMENTS

- All areas will be highly competitive.
- All the above design considerations will undergo significant improvements over the next ten years, primarily due to more sophisticated CAE tools.
- Basics are: quality, reliability, dependability, and performance. Differentiators are: price, features, styling, and product development cycle.
- CAD/CAM should revolutionize the way cars are manufactured. This must be our direction in order to compete internationally.
- Expect that the market demand for trucks will energize all the above influences, similar to current activity in passenger cars.

- I believe the North American market has a more fragmented buying group for particular products than the Japanese and Europeans. The Japanese market is driven by change and new technology, whereas the European market is more performance-driven. The North American market has all that plus those who purchase for function, style, or status. If we have all the tools to make "high-tech" vehicles, per this question, we could go overboard and miss a lot of the traditional market.
- Major changes in the process of creating a new design with more optimization using CAE, CAD, and CAM.
- New technologies in materials, processes, and assembly systems or modularization will influence these designs the most.
- Only competition can sway current U.S. automakers' theory on new developments. Theory says "new stuff must be better and cheaper, or forget it." Cheaper is good (demand) but just better is not sufficient reason for chance. Hence the technological "follow the leader, then market it" approach of domestic auto industry.
- Perceived aerodynamics will be more important than actual. Image will be critical, i.e., What's Hot! Fads! California!
- Quality ranks medium because quality will be an entry consideration.
- Real "world-car" commonality in design and major specifications will become a necessity.
- Simultaneous research, development, and engineering manufacturing must be practiced to bring products to market faster.
- Speed to market will heavily influence the engineering/development process.
- The design process must accommodate more and more differentiation and more rapid product development.
- Turnaround time must be cut 50% to 60% from current methodologies.
- Vehicle design is a marketing not a technically dominated function.
- Where is price/value—ultimately what a vehicle sells for must dictate what it can cost.

MANUFACTURER/SUPPLIER COMPARISON

There are no significant differences between the responses of the OEM and supplier panelists. The median percents forecast by both groups varied no more than 5%.

TREND FROM PREVIOUS DELPHI SURVEYS

A review of the trend data reveals a relative consistency in the opinions of a series of Delphi panelists regarding their perceptions of the importance of various factors influencing light-duty vehicle design. This is readily apparent in their choice of quality and foreign competition as the leading factor in three successive Delphis.

Factors	Ranking by Degree of Influence		
	1989 Delphi V	1987 Delphi IV	1984 Delphi III
Quality	1	1	1
Foreign Competition	2	2	2
Market Demand	3	3	8
Styling	4	6	5
Durability	5	7	6
Cost of Manufacture (non-labor)	6	4	4
Performance	7	8	7
Labor Cost	14	5	3

STRATEGIC CONSIDERATIONS

When compared to prior Delphi forecasts, there is general consistency in the expectations of the Technology panelists with regard to this issue. There is, however, one notable shift from past forecasts. Compared to Delphi IV, the first three factors of quality, foreign competition, and market forces continue as the three primary factors shaping vehicle design. It is noteworthy that labor cost has fallen significantly and styling has increased in relative basis of importance. The reduced level of labor is indicative of a broader understanding of the total cost structure as well as improvements in such areas as labor productivity. A true systems approach to the design process will appropriately include all of these factors as well as perhaps some not on this list. Some factors such as safety or fuel economy may receive an evaluation of medium influence, but this rating is, in a sense, academic, since regulatory considerations ensure their importance. A certain minimum level of performance is required to even permit production.

In summary, it is evident that market-related forces will have a dominant influence on future automotive products. In fact, many factors in a lower ranking in the list could be viewed as a subset of the highest-rated factors.

TECH-14a. Among the traditional domestic, U.S.-owned vehicle manufacturers, what percentage of product design and engineering is, and will be, performed domestically in the years listed? What percentage will be performed offshore?

U.S.-Owned Product Design and Engineering	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
Domestic	85%	80%	75%	80/90%	70/85%	65/85%
Offshore	15	20	25	10/20	15/30	15/35

SELECTED EDITED COMMENTS

- Centers of expertise will be developed globally.
- More design work will shift from OEM to suppliers.
- Trend assumes more outside engineering work in general—sourced in U.S. and overseas. Ford continuing their worldwide center of expertise plans for design.
- Trend is to brokerage engineering to offshore divisions/affiliates.
- U.S. OEMs must retain those research, development, and engineering areas that provide their models with character (powertrains, suspension systems). With too much outsourcing you lose this ability.
- Percentage of domestic design and engineering will decrease moderately in 1995, much more in 2000 if exchange rates remain stable or favor the dollar.
- World car designs will lead increasingly to one design location for a given vehicle segment, i.e., design mid-size in Europe for worldwide manufacturing and sales.
- U.S. suppliers will contribute engineering to offshore-owned manufacturers.
- Unless consortium efforts among U.S. manufacturers are allowed to occur and even be encouraged, the above estimates could be off by at least 25%.

MANUFACTURER/SUPPLIER COMPARISON

There is no significant difference in the forecasts of the manufacturer and supplier panelists. Where differences did occur, they were between 2%–5%.

TREND FROM PREVIOUS DELPHI SURVEYS

Year	Domestic		Offshore	
	1987 Delphi IV	1989 Delphi V	1987 Delphi IV	1989 Delphi V
Current Estimate	90%	85%	10%	15%
1990	80	N.A.*	20	N.A.
1995	75	80	25	20
2000	N.A.	75	N.A.	25

*Data not available.

STRATEGIC CONSIDERATIONS

The panelists forecast a trend to sourcing of engineering outside of North America by the domestic manufacturers. However, the percent is less than was suggested in Delphi IV. Nevertheless, by the year 2000, about 25% of the traditional American manufacturers' engineering is expected to be done offshore. This seems consistent with the trends on the part of both major manufacturers and suppliers to become far more globalized in their approach to the product development process and the ability to exchange data electronically on a global basis. This trend continues to raise concerns about the North American industry losing key centers of expertise and technical capabilities.

Perhaps the more significant question related to this issue is the shift of engineering from the manufacturers to the outside supply base. For competitive reasons, manufacturers and suppliers must utilize the best and most efficient engineering resource available to them. To do otherwise could jeopardize their position in the marketplace. One would hope, however, that sufficient capacity can be found in the United States and Canada.

An important factor in the distribution of engineering on a country basis is the engineering service sector of the industry and whether it has sufficient domestic capacity and skill to meet the demands of their customers. Another issue is related to the efficiency/ speed of the product development process. If a dramatic reduction in lead time can be achieved, this would suggest that the engineering process is more efficient, requiring fewer people for a given task. This could bring a greater fraction of the engineering back to North American engineering centers if appropriate knowledge and skills are available.

TECH–14b. Among North-American-based, but foreign-owned vehicle manufacturers, what percentage of product design and engineering is, and will be, performed domestically in the years listed? What percentage will be performed offshore?

Foreign-Owned Product Design and Engineering	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
Domestic	10%	15%	25%	5/10%	10/25%	15/35%
Offshore	90	85	75	90/95	75/90	65/85

SELECTED EDITED COMMENTS

- Computer technology—for design and manufacturing—will expand to give domestic designers and engineers a competitive edge, but political and economic conditions must be improved by government to allow for this to happen. The right incentives and atmosphere must prevail.
- Japanese and Europeans will continue to do most of their engineering in the home location. Selected R&D and styling/design will be done outside their home location.
- Nationalism in Japan and Europe will limit this for some time to come.
- Not likely that the Japanese will do a serious amount of "off-shore" engineering outside Japan because they see no advantage in it aside from small groups to "gather information."
- Resources are not increasing to cover both domestic and overseas producers fast enough.
- Will see a reversal of trend in TECH–14a, i.e., offshore-based (Japanese) companies will set up R&D and tech centers in U.S.

MANUFACTURER/SUPPLIER COMPARISON

The supplier panelists forecast 20% for domestic in 1995 and the OEM panelists forecast 20% domestic for the year 2000. There was agreement on the other yearly forecasts.

STRATEGIC CONSIDERATIONS

Foreign manufacturers producing vehicles in North America are expected to conduct most of their product engineering functions outside of North America. However, there is a definite trend to an increased level of engineering in North America and, in fact, by the year 2000, fully 25% of the new American manufacturers' engineering function is expected to be in North America. This important trend suggests that the transplant manufacturers are becoming more deeply committed to full participation in the North American industry. However, they will retain a significant portion of key engineering capabilities in their own domestic laboratories. As the North-American-based engineering capabilities improve and demonstrate an ability to interface across national boundaries, the percentage of North-American-sourced engineering could expand significantly. It will be interesting to watch how the various Japanese firms, in particular, divide their engineering effort both on a component/subsystem basis and national origin of engineering. Several of these firms are giving strong indications they will be more aggressive with North American sourcing. The key issue will be whether they will accept movement of intellectual control away from their own major centers of expertise. Ultimately competitive pressures will dictate that engineering will be sourced where it can be done the best, at the lowest cost, and most quickly.

TECH-15a. If there is no domestic content legislation for the United States, what percentage of parts, components, subassemblies, etc., purchased (dollar volume basis) by domestic U.S.-owned manufacturers will be sourced outside North America in the years 1995 and 2000? Please include a current estimate.

Outside Parts Source	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
Japan	10%	8%	8%	8/10%	7/10%	5/10%
Korea/Other Asia	3	5	7	2/4	4/7	5/10
Mexico/South America	5	9	10	5/6	7/10	8/12
Western Europe	3	3	3	2/3	2/4	2/4
Other	0	1	2			
TOTAL	21%	26%	30%	19/22%	22/28%	23/33%

SELECTED EDITED COMMENTS

- No local content laws are likely to change trend to Mexico and South America.
- Offshore trend will stabilize or diminish as the foreign costs and shipping costs increase.
- Sourcing outside of the U.S. will continue to increase if legislation and labor union constraints do not block it.
- This question will be driven by currency fluctuations and the trend toward regional manufacturing capability to take advantage of exchange rate shifts.
- This question depends upon the relative value of the dollar with a lag of several years to get production in place. However, Korea and Latin America will remain sources due to low labor costs.
- "The bloom is off the rose." Korea is too unstable and will blow up, Japan too expensive, Europe too arrogant. Mexico and South America if left alone by communists will increase.
- As the industry becomes more global, the trend will be to source outside the U.S., but that will be offset by lower costs and psychological trends favoring the U.S.
- CAFE laws will force offshore sourcing to avoid factoring large cars in CAFE calculation.
- Even without legislation, the UAW will have a say in this.
- Influenced by exchange rates, the development of the automotive parts industry in India and China, and impact of the EEC marriage.
- I don't feel there is a significant commitment to offshore purchasing even if measurable cost savings exist.
- Increases in quality, variation reduction, cost/value issues, and responsiveness in U.S. will lead to reduction in outsourcing.
- Is not clear if intent is only if the component is produced outside U.S. or manufactured by a company offshore-owned. U.S. component companies also manufacture offshore for sales in U.S.

- Japanese share depends on yen/dollar parity. Correction seen in 1995–2000 period.
- Korea, Mexico, and South America will be favored on cost; Japan and Europe, on technical specialty.
- Wages in Korea/Mexico will surely increase in the next decade, thereby reducing the cost advantage.
- More offshore manufacturers and suppliers will build in the U.S., accelerated by the weakness of the dollar. These will be mostly Japanese and German.
- Asia and South America will increase as sources because of low labor costs.
- Devaluation of dollar compared to foreign currencies will keep U.S. percentage very high through turn of century. Foreign/U.S. joint ventures will keep supply base largely within North America.
- An aggressive Korean industry will pick up business, as will the Pacific Rim. Underdeveloped countries will pick up electrical/electronic subassembly business. New EEC rules will divert some additional European exports to internal European commerce. Parity issues will still dominate decisions.
- China may be a major player by 2000.
- CAFE may push more "gas guzzler" vehicles to use offshore components.
- Expect push to not source in Japan/Asia because of stability of dollar/yen along with pressure to buy American.
- Mexico and South America areas appear to be the prime source of low-cost assemblies to the U.S. market.
- Reduced vehicle production in Japan will force parts exports.
- Sourcing within the U.S. will be more desirable due to currency factors.
- The dollar/yen relationship will continue to be the determining factor regarding Japan as a component source. The national stability of Korea will form the basis for future component business expansion in that country. The other newly industrializing countries do offer low-wage rate-production opportunities: Thailand, Vietnam, and expanding relations with China. However, even with these new sources, I believe the predominant low wage source will be Mexico because of its proximity and its emerging governmental dependency as a function of its trade balance.
- Weakening of dollar due to trade imbalance. Trade deficit is the cause for increased domestic content in the short term. Continued sourcing to Mexico and South America is expected because the dollar is strong against those currencies and labor costs are low. Unsure where dollar/yen relationship will go.
- Domestic supply base is improving dramatically.

MANUFACTURER/SUPPLIER COMPARISON

There exists a remarkable agreement between the manufacturer and supplier panelists regarding forecast for individual source categories. The only difference is in regard to Mexico/South America for 1995. In that forecast, the suppliers projected 10%, whereas the OEM panelists forecast 8%. There was also some disagreement on the total median percent. The supplier panelists forecast 28% for 1995 and 30% for the year 2000; the manufacturer panelists forecast 26% for 1995 and 28% for the year 2000.

COMPARISON OF FORECASTS: MKT-45

As illustrated in the following table, although the percent difference may appear small, a significant difference of opinion exists between the Technology and Marketing panelists with regard to the off-shore sourcing of automotive components. The Marketing panelists forecast a much smaller total percent foreign-sourced parts and components than did the Technology panelists.

Outside Parts Source	Current 1990 Forecast		Forecast for 1995		Forecast for 2000	
	Mkt Panel	Tech Panel	Mkt Panel	Tech Panel	Mkt Panel	Tech Panel
Japan	9%	10%	8%	8%	7%	8%
Korea/Other Asia	2	3	3	5	5	7
Mexico/S. America	3	5	4	9	4	10
Europe	3	3	3	3	3	3
Other	0	0	0	1	0	2
TOTAL	17%	21%	19%	26%	20%	30%

TREND FROM PREVIOUS DELPHI SURVEYS

As illustrated in the following table, there is a significant reduction in the Delphi V 1995 median forecast for percent of parts, components, subassemblies, etc., sourced offshore when compared to Delphi IV. It should be noted that Canada was not included in the Delphi V survey. However, even factoring in the largest percent forecast in the previous Delphi for Canada, there would still exist a considerable reduction in the total median percent forecast.

Outside Parts Source	Forecast for 1990				Forecast for 1995	
	1979 Delphi I	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
Canada	N.A.*	9%	8%	5%	7%	N.A.
Western Europe	N.A.	4	4	5	5	3
Japan	N.A.	8	9	10	10	8
Korea/Other Asia	N.A.	4	3	5	10	5
Mexico/South America	N.A.	8	6	5	9	9
Others	N.A.	4	0	0	0	1
TOTAL	15%	37%	30%	30%	41%	26%

*Data not available.

STRATEGIC CONSIDERATIONS

Delphi V panelists have indicated they expect a rather significant decrease in the level of sourcing outside of North America, compared to the forecast in Delphi IV. However, anticipated off-shore purchases on a dollar-volume basis will still be very significant, particularly from Latin America and the Far East. Numerous factors critically influence this forecast. They include: trends in the exchange rates, increased competency of the North-American-based supplier network, the movement of foreign-owned suppliers to North America, trends in joint-venture relationships, shifts in vertical integration on the part of the automotive manufacturers, labor agreements providing high levels of job security, trends in commodity pricing, and political stability, or lack thereof, in various areas of the world. Obviously, this is not a simple issue. However, the bottom line is that North American manufacturers, both traditional domestics and transplants, must do everything possible in their component purchasing strategy to assure long-term success. Price, quality, delivery, and engineering capability will be some of the more important factors manufacturers must use in their sourcing decisions; in effect, a move from price-based to value-based purchasing. We anticipate offshore sourcing to continue as a very volatile issue throughout the next decade.

TECH-15b. If there is no domestic content legislation for the U.S., what percent of parts, components, subassemblies, etc., purchased (dollar volume basis) by North-American-based but foreign-owned vehicle manufacturers will be sourced within the U.S. and Canada and what percent will be sourced outside North America?

Parts Source	Median Response		Interquartile Range	
	1995	2000	1995	2000
U.S./Canada	37%	50%	35/40%	45/60%
International	63	50	60/65	40/55

SELECTED EDITED COMMENTS

- Highway engineered, high-labor-content assemblies will remain outside U.S. unless domestic content legislation forces this issue for all but the largest producers (e.g., Honda, Nissan). U.S. needs uniform guidelines established to determine "local content."
- The Japanese relationships with their home-based suppliers will only very gradually give way to U.S. sources. It takes years of work and cultivation before the new relationships gel and a domestic supplier earns their confidence and demonstrates quality and service to their satisfaction. This restraining situation is balanced by the yen/dollar parity issue.
- Transplants will source domestically, driven by costs and profits as much as political pressure. U.S. is becoming a cheap-labor, low-technology source for the world!
- U.S. will only get better. U.S. dollar, in U.S., is stable.
- Doubt that dollar weakness will support investment beyond 30% to 35% of total sourcing for all manufacturers.
- Japanese will do more final assembly in the U.S. (e.g., vehicles, engines and transmissions). Components will continue to be manufactured outside the U.S.
- Local content ought to reflect only real engineered assemblies such as powertrains and engines.
- Obviously will depend on (1) exchange rates between U.S. dollar and foreign currencies, and (2) U.S. local content requirements.
- This question depends upon the relative value of the dollar along with a lag of several years to get production in place. Korea and Latin America will remain sources due to low labor costs.
- U.S. manufacturing now is very cost competitive. Percentages presume no major change in relationship between dollar and yen/deutsche mark.

MANUFACTURER/SUPPLIER COMPARISON

Both the OEM and supplier panelists were in agreement with the median responses.

COMPARISON OF FORECASTS: MKT–46

The Marketing panelists forecast that North-American-based but foreign-owned vehicle manufacturers would source a significantly higher percent of parts, components, etc. from the U.S./Canada than did the Technology panelists. See table below.

Parts Source	Forecast for 1995		Forecast for 2000	
	Technology Panel	Marketing Panel	Technology Panel	Marketing Panel
U.S./Canada	37%	60%	50%	56%
International	63	40	50	44

TREND FROM PREVIOUS DELPHI SURVEYS

As illustrated in the trend table below, Delphi V panelists have increased their forecasts over those of Delphi IV for sourcing of parts, components, and subassemblies, etc., purchased by U.S.-based but foreign-owned vehicle manufacturers (NAMs) that will be sourced within the United States and Canada.

Parts Source	Percent Sourced in 1995	
	1987 Delphi IV	1989 Delphi V
U.S./Canada	30%	37%
International	70	63

STRATEGIC CONSIDERATIONS

Delphi V panelists have increased optimism with regard to sourcing of components in North America by transplants or New American Manufacturers (NAM). This is evident in the increased expectations for North American sourcing in 1995, compared to prior Delphi IV forecasts. Still, only about 50% of the components, on a dollar-volume basis, are forecast to be produced in North America by the year 2000. This probably will not be sufficient to diffuse growing pressure on the NAMs to source more extensively in North America. One wonders how this forecast will be split between the new American suppliers and the traditional American suppliers.

A key factor, obviously, is the trend in exchange rates, particularly between the yen (despite recent $/yen exchange rate movements) and dollar. It appears that with continued strengthening of the yen and improving quality of components produced by American industry, domestic sourcing could increase more than is forecast. Based on a number of personal contacts with executives of Japanese manufacturers, we sense a growing commitment to North-American sourcing. However, at best, a slow rate of increase is anticipated due to the importance placed on existing relationships and the difficulty with which new relationships are established. Furthermore, there still seems to be a good measure of skepticism on the part of Japanese manufacturers with regard to the traditional U.S. supply base capability.

A further factor is the growing trend to joint venture relationships between foreign and domestic suppliers. In fact, executives at some foreign companies have been actively encouraging such ventures in order to appease their traditional supply base as well as purchase from more politically acceptable North American suppliers. We continue to believe that the key message for any North American supplier in dealing with the Japanese is patience and perseverance and, of course, competitive cost, quality, delivery, and technology. Relationships must be carefully nurtured and aggressively pursued.

TECH-16. What percentage of North-American-produced passenger vehicles will use an integral frame or other design in model years 1995 and 2000?

Design	Median Response		Interquartile Range	
	1995	2000	1995	2000
Integral Body/Frame or Unibody	92%	92%	90/93%	85/95%
Space Frame/"Bird Cage"	2	4	1/4	1/10
Separate Body/Frame	6	4	5/7	3/6

SELECTED EDITED COMMENTS

- Due to efficiencies in steel construction, don't expect much increase in space-frame/plastic-panel construction.
- Full frame rear-wheel-drive just won't die!
- Isolated sub-frames for mid-size to large cars will continue.
- Manufacturing, cost, and safety/regulatory considerations will hinder pace of change.
- New materials will require a frame for support but 1995 is too soon to make change.
- New GM mini-van is only space frame.
- Plant conversion cost will be a factor slowing down change to space frame.
- Space-frame percentage may go up faster, depending on metal bending and welding technology.
- Space frame and separate body/frame are wrong, but inertia will increase their use. Too bad.
- Unibody with module for assembly will be utilized, based on cost.

MANUFACTURER/SUPPLIER COMPARISON

There are no significant differences in the median forecasts between the OEM and supplier panelists. However, the upper interquartile range forecast for space frame in the year 2000 is 10% for the manufacturer panelists and 5% for the suppliers. There was no significant difference in the separate body/frame forecasts.

TREND FROM PREVIOUS DELPHI SURVEYS

In the previous Delphi IV survey it was forecast that integral body/frame would be 90% and space frame would be 7% by the year 1995.

STRATEGIC CONSIDERATIONS

The integral body/frame design is expected to be the dominant vehicle body construction technique through the year 2000. In fact, 92% of vehicles are forecast to use this construction. A modest but growing role is expected for the space frame but a slightly decreased role is anticipated for the separate body/frame design.

Generally, the results were consistent with the forecasts in Delphi IV but with a modestly downgraded expectation for space frames. It is important to note that as the automotive materials revolution accelerates in the 1990s, the basic construction techniques of the body structure could be altered rather significantly as new technologies emerge near the latter part of the next decade.

An interesting recent development is the recognition that significant improvements can be made in fabricating the body-in-white by taking a true systems approach to the problem. Factors being considered include the product development process, improved material quality, new tooling techniques, and very importantly, streamlined management practices. The success of the North American auto and steel industry partnership in addressing these systemic issues could become a model for cooperation between key elements of the industry.

Since space-frame technology is near the front end of the learning curve, trends will have to be watched very closely. This uncertainty or lack of predictability is reflected in the rather broad percentage variation in the interquartile range for the year 2000. This certainly is due, in part, to the variation in experience between the manufacturers in space-frame technology.

TECH-17. What are some of the key factors limiting the future use of space-frame vehicle? Please comment.

Key Factors Limiting Space-Frame Vehicles	Percent of Total Responses
Cost	39%
Volume/Capacity	14
Body-Panel Fit	9
Weight	9
Safety/Crashworthiness	9
Cost of Repair	6
Consumer Attitudes	6
Production/Assembly Considerations	4
Development of Composite Technology	4
Other:	
Lead Time	
Overcapacity of industry	

REPRESENTATIVE RESPONSES

- Volume: low volume will make cost viable; product life-cycle: frequent styling change will help this construction; product assembly methods: space-frame will increase if expensive mill/drill is not needed due to increased variation control.
- Assembly fixturing is a limitation.
- Cost for large-volume models. Weight for large-sized cars. Tolerances in metal space-frame are not good enough for required fit and finish quality when unforgiving plastic panels are used for skin (exotic, expensive mill and drill machine on Fiero line).
- Cost to retool manufacturing facilities since space frames have been primarily limited to low-volume platforms. Limited weight savings.
- Crashworthiness vis-a-vis government laws.
- Development of high-strength and low-cost composites.
- Distortion of frame.
- Existing facilities (investment) dedicated to conventional (unibody) vehicle construction. Reluctance to change.
- Integrity of structure under all conditions (fatigue, corrosion, etc.) and crashworthiness (occupant protection).
- Major assembly plant impact. Higher cost for assembly.
- Modular-build concepts may spur increased interest in space-frame concepts.
- Only inertia in thinking is limiting use of space-frame.
- Public (consumer) wariness. Not suited for high-volume production.
- Recent major investments in transfer lines and large presses for integral body/frame vehicles.
- Ride and harshness.

- Space-frame usage will be enhanced as composite technology is improved. As long as crashworthiness must be satisfied by the substructure, space frames will lag.
- The present large investment in conventional vehicle construction technology will hinder efforts to invest in new plants, machines, and equipment for space-frame construction. Projected overcapacity in North America also does not help.
- This is "code word" for plastic skin. Cost and quality are major limitation of plastic skins.
- Too heavy for structural benefits added. Quick redesign or changes to panels are not so easily accomplished as first thought. Concern for additional cost exists.
- Towing capacity, cost of body repairs, and therefore insurance.
- Unibody construction is probably much cheaper and easier to assemble.
- Use of robots to reduce labor and improve precision. Ability to mount composite skins.

STRATEGIC CONSIDERATIONS

There is no question that considerable uncertainty exists with respect to the future use of space-frame vehicles. The primary concern of cost is very evident in the responses to this question, although by no means are some of the other issues resolved, e.g., volume, capacity, weight, body-panel fit, and safety concerns. Consequently, some of the newest developments such as the General Motors mini-van (APV) must be watched very closely in terms of how these concerns are addressed. At this point, it does not appear that the customer perceives value in any particular type of vehicle construction; they are more interested in overall function, durability, and performance. The various comments in this question are a good indication of the concerns within the industry. Obviously, substantial growth in the use of the space-frame concept would have a dramatic impact on a number of automotive suppliers.

TECH–18. What percentage of North-American-produced passenger cars will incorporate the following suspension features in the areas indicated in the years 1995 and 2000?

Suspension Features	Median Response		Interquartile Range	
	1995	2000	1995	2000
Front Suspension				
MacPherson Struts	80%	75%	80/85%	70/80%
Twin A-Arm	20	25	15/20	15/30
Rear Suspension				
Independent	50	60	50/60	50/75
Non-Independent	50	40	40/60	30/50
Damping				
Present System	80	70	80/85	65/75
Electronically Controlled Passive	10	15	5/12	10/20
Electronically Controlled Active	5	10	1/5	3/10
Driver Controlled	5	5	2/5	4/10
Springs				
Air	5	5	3/6	4/10
Oil/Fluid	2	3	2/3	2/5
Composites	5	10	4/6	7/15
Steel	88	82	85/90	73/82

SELECTED EDITED COMMENTS

- Driver-controlled system will gain popularity on upper-middle range passenger cars. So electronic control of suspension is inevitable.
- Electronic suspensions are next major impact. Springs will go heavily to composites—they work!
- Electronically controlled suspension will be more attractive if luxury/large cars are downsized for CAFE. They carry a larger payload with good ride and handling. Technology breakthroughs required for widespread use of active systems.
- Electro-rheological (ER) fluids are the key to low-cost active systems.
- "Active" suspension is overrated and too costly. Expect very limited use.
- Cost premium for electronic-controlled systems versus the present system cost will be the primary inhibition to wider-spread applications.
- Electro-rheological fluids may be introduced in the mid-1990s as a damping medium.
- I believe electro-rheological fluid devices will capture a major portion of the motor-mount and shock-absorber market.
- Other suggested suspension features: composites; pneumatic pillow or horizontal torsion bar type; trailing link; transverse leaf.
- For totally active suspensions to achieve application rates much beyond 1%, major technological advances are required to significantly reduce costs and weight.

- New designs will be formulated based on CAFE.
- Passive electronic systems will not progress much. Drivers will want to interact. Letting the system do it on its own will not be desirable (or discernable enough for that matter).
- Twin "A" arms will return due to friction issues with struts.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in general agreement on forecasts for front and rear suspension configurations and present and electronically controlled passive damping systems for both 1995 and 2000. Where differences exist in the remaining categories, they do not exceed 1%–2%.

TREND FROM PREVIOUS DELPHI SURVEYS

The following trend analysis data was extracted from several different Delphi IV questions. With the exception of independent rear suspension, there is a dramatic reduction in current Delphi expectations for various chassis/suspension features. See also TECH–19a and TECH–19b.

Suspension Features	Forecast for 1995	
	1987 Delphi IV	1989 Delphi V
Independent Rear Suspension	50%	50%
Driver-Controlled Damping	15	5
Air Springs	10	5
Oil/Fluid Springs	5	2
Composite Springs	20	5
Electronically Controlled Active	20	5

STRATEGIC CONSIDERATIONS

Interesting and important developments are forecast in the basic chassis of North American vehicles within the next ten years. In the front suspension, MacPherson struts, which have become dominant, are envisioned to fade modestly with a resurgence in the use of twin-A arm designs. This is due, in part, to the renewed interest in rear-wheel drive vehicles and the development of novel suspension designs (such as those on several Japanese cars) for front-drive vehicles.

A significant shift to independent rear suspensions is occurring. However, non-independent designs with their basic simplicity and low cost will be used extensively. A relatively significant increase is expected in variable suspension damping systems and the increased use of non-metallic springs. In general, there will be a far greater variety of chassis/suspension componentry than has been observed in the last decade. Of course, increased sensitivity to the voice of the customer will be a strong factor influencing decisions aimed at optimizing perceived value in terms of ride, handling, and cost. Today's customer is more demanding with high expectations, which will probably dictate a higher level of refinement in future suspension/chassis systems. If customers readily accept the new technologies, such as active, electronically controlled damping, usage could expand considerably beyond the present forecasts. However, by no means is this a certainty. We expect the chassis/suspension area will continue to be a volatile area with respect to new technologies and it must be watched closely by component suppliers. With this in mind, the panelists' comments presented with this question should be studied carefully.

TECH-19a. What percent of North-American-produced passenger cars will have the following chassis/suspension features in the years listed?

Passenger Cars: Chassis/Suspension Features	Median Response		Interquartile Range	
	1995	2000	1995	2000
Electrical/Electronic Power Steering	10%	20%	5/10%	10/25%
Active Four-Wheel Steering	5	8	2/5	5/10
For Ride/Handling Mode:				
Passive Control	84	73	75/88	60/79
Passive-Driver Selected	10	13	5/10	8/15
Semi-Active	4	8	3/5	5/10
Active	2	6	1/3	2/10

SELECTED EDITED COMMENTS

- More technology will provide components, but cost will limit new technology to high end of market (four-wheel steering, ride/handling adjustment suspension).
- No significant trend, cost prevents it.
- Passive-driver select and semi-active overlap—driver selects "mode," system does rest.
- Ride/handling mode systems are, and will continue to be, considered to be discretionary "gimmicks" by customers.
- Four-wheel steering will receive wide acceptance quickly after BMW and Mercedes start use; will be seen as safety feature like ABS.
- Four-wheel-steering is likely to remain a gimmick, especially since so few U.S. car drivers regularly make 80 mph slaloms.
- Four-wheel steering is, for now, a complex technology with little practical use. Integrated active suspension with modes for varying conditions is the right answer, but high costs will delay its implementation.
- With an increase of 0.3 to 0.4 mpg, the CAFE incentive is too great to not use electronic/ electric power steering.
- Cost versus benefits of four-wheel steering and "trick" suspensions simply do not match. If we all drove Winston Cup cars the answer would be different.
- Electric power steering still has a way to go. Claims have exceeded the facts thus far.
- Electrical steering requires much more power than is currently available from present electrical systems. This technology will force a redesign/invention of other systems.
- Four-wheel steering is a fad—not much consumer benefit except for high-speed sports cars and large family autos (ease of parking). Need to stay pure on definition of "active," i.e., put energy into suspension. All others are passive. There is no such thing as semi-active.
- Introduction of active/semi-active suspension will depend on cost—needs to be of same order as air conditioning.
- Four-wheel steering will return to "gimmick status" as better rear suspensions are developed.

- Four-wheel steering is going to prove to be functionally attractive despite current "gimmick" accusation by "know-nothings."
- Four-wheel-steering advantages for city parking maneuvers will be a driving force, not only high-speed swerve control. ER fluids in active suspensions will make them cost effective but much technical work remains; therefore, not before 2000.

MANUFACTURER/SUPPLIER COMPARISON

The supplier panelists' electronic power steering forecast for 1995 is in agreement with that of the OEM panelists. For the year 2000, the supplier panelists forecast 25%, while the OEM panelists were in accord with the presented median. The interquartile ranges of both groups are very tight, indicating a substantial degree of agreement within each panel.

COMPARISON OF FORECASTS: MKT-39

Marketing panelists forecast that the median North American passenger car market penetration rate for active four-wheel steering may be 1% for 1995 and 3% for the year 2000. Active suspension control is forecast to be 4% in 1995 and 5% by the year 2000. The interquartile range for 1995 is very good; the range for 2000, however, is not as tight, with 4% for the lower quartile. There is no Marketing forecast for electronic/electric power steering.

TREND FROM PREVIOUS DELPHI SURVEYS

Chassis/Suspension Features	Forecast for 1995	
	1987 Delphi IV	1989 Delphi V
Electronic Power Steering *	25%	10%
Active Four-Wheel-Steering	5	5
Active Suspension *Ride Mode***	15	
Active Suspension *Handling Mode***	10	
Driver-Selected Ride/Handling Mode**	20	
Electronically Controlled Active Suspension**	20	

*Delphi IV forecasts for these chassis/suspension features are from a question that combined cars, vans, and light trucks. The Delphi V forecasts are only for passenger cars.

**A Delphi IV question regarding penetration rates of chassis/suspension systems in U.S.-produced passenger cars specified only for active suspensions in a mechanical/electrical ride mode and a handling mode. While these categories are not precisely comparable to those of Delphi V, they are sufficiently close to be presented as relevant trend data.

STRATEGIC CONSIDERATIONS

The present Delphi V data indicates that several technologies viewed optimistically several years ago have been downgraded in terms of future expectations. Electric/electronic power steering, for example. The forecast for acative four-wheel steering is consistent with the Delphi IV forecast, but expectations still remain low in terms of total application level. There is more modest enthusiasm for semi-active and active suspensions than was evident in earlier Delphis, although the data are not strictly comparable. Still, a number of advanced chassis technologies are expected to be used in significant numbers during the next ten years and will be particularly important in providing product differentiation. For example, high-tech, sporty, and high-performance cars are likely to use active and semi-active suspensions as important differentiators. This may be true also with active four-wheel steering. With renewed interest in increased CAFE standards, larger luxury cars may face some downsizing/downweighting, which could strengthen demand for features that preserve large-car ride and feel.

There is no question that the basic cost/benefit issue related to all of these technologies will be crucial regarding their ultimate application in light-duty vehicles. It is also worth noting that the functionality of present-day chassis/suspensions is outstanding and continuing improvements are being made. Developments in this area must be watched very closely because market forces may emerge that could prompt significant shifts in demand. The comments in this question suggest there are diverse and often conflicting views on these chassis/suspension features.

TECH-19b. What percent of North-American-produced light trucks will have the following chassis/suspension features in the years listed?

Light Trucks: Chassis/Suspension Features	Median Response		Interquartile Range	
	1995	2000	1995	2000
Electrical/Electronic Power Steering	5%	10%	1/5%	5/15%
Active Four-Wheel Steering	0	2	0/0	1/4
For Ride/Handling Mode:				
Passive Control	93	86	90/95	80/90
Passive Drive Selected	5	8	2/5	5/10
Semi-Active	2	5	1/3	2/5
Active	0	1	0/1	0/3

SELECTED EDITED COMMENTS

- Do not see market for "high-tech" suspension/steering in truck area. Electrical power steering provides cost reduction, weight, and packaging potential advantages best achieved with a new model.
- Features are needed for driver benefit; however, the trucks that need them the most are seldom driven by the owner.
- There is a greater need and desirability for these features in trucks.
- Light-truck owners are likely to be attracted to driver-selected shock absorber settings.
- Load-sensitive suspensions (semi-active) are likely.
- The major reasons for electric steering are: packaging and fuel economy; neither are big issues in light-duty trucks.
- Will depend on degree of continuing penetration of trucks into today's passenger car market. These people will pay for the ride/handling features. Utility vehicles might benefit from four-wheel steering.
- There will be minimal application of these features on trucks.
- Suspension control offers trucks more benefit than car.
- Major ride/handling fault in light trucks is the compromise between laden and unladen conditions.
- Semi-active and active suspensions will appear on premium sport-utility vehicles.
- Very limited benefits of four-wheel steering will limit its desirability.

MANUFACTURER/SUPPLIER COMPARISON

The supplier panelists are in agreement with the consensus forecasts for all the chassis/suspension features surveyed. The manufacturer panelists, with the exception of electronic power steering, were either in agreement with the consensus forecasts or within 1%. For electronic power steering, the OEM forecasts are 3% for 1995 and 8% for the year 2000. The OEM interquartile range for 1995 is quite tight. The interquartile range of 4/20% for 2000 indicates a considerable degree of uncertainty as to maximum market penetration.

TREND FROM PREVIOUS DELPHI SURVEYS

See *Trends* section in TECH–19a.

STRATEGIC CONSIDERATIONS

Compared to passenger cars there is considerably less enthusiasm for various advanced chassis/suspension features in light trucks and vans. However, considering how many people use these vehicles in a manner similar to passenger cars, there exists a significant level of future interest. We suspect that developments applied initially to the passenger car will spread rather quickly to light trucks and vans. Clearly, the development of cost-effective technologies and market forces will be the primary determinants in future application of these chassis/suspension features in light trucks.

TECH-20. What percentage of North-American-produced cars, light trucks, and vans will use rear disc brakes in 1995 and 2000?

North American Vehicle	Percent Using Rear Disc Brakes			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Passenger Cars	10%	20%	7/10%	15/20%
Light Trucks	1	5	1/3	4/7
Vans	2	5	1/4	5/10

SELECTED EDITED COMMENTS

- Parking brake legislation in certain states must be updated for complete disc-brake usage on rear wheels.
- As cars get lighter, well-engineered rear-disc systems should become equal to or less than cost of drum systems. I would then look for them as major system upgrade.
- Situation will be much like front disc brakes—a wholesale change.
- Anti-lock rear systems obviate the need for rear disc brakes.
- Continue to feel that there is a major move to rear disc brakes in passenger cars.
- I think increased ABS and traction control will increase usage of discs in rear.
- Lower cost rear disc systems will increase installation rates. Also, traction control will tend to drive usage upward as well as the associated weight reduction.
- With front-wheel drive still being the largest percentage of drivetrain layout, rear wheel discs will not be necessary. Front brake improvements will be the major change.

MANUFACTURER/SUPPLIER COMPARISON

There is modest disagreement between the manufacturer and supplier panelists regarding the application of rear disc brakes in passenger cars: the supplier panelists forecast 7% by 1995, the OEM panelists forecast 16% for the year 2000. There is almost complete agreement on the other forecasts with close interquartile ranges.

TREND FROM PREVIOUS DELPHI SURVEYS

Use of	Forecast for 1990			Forecast for 1995	
	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
Rear Disc Brakes	30%	30%	20%	40%	10%

STRATEGIC CONSIDERATIONS

A significant reduction in the expected trend to rear disc brakes in light-duty vehicles by 1995 was observed in the current Delphi V compared to Delphi IV. Yet, the altered forecast represents a significant increase in the use of rear disc brakes compared to today. There are substantial differences between the two brake systems (brake versus drum). This could affect the supply base significantly. Any technological shift such as this should be viewed both as a threat and an opportunity. Unless the vehicle is directed at high performance or "up-tech" segments of the market, the reduced expectations for rear disc brakes can be traced to lack of perceived value on the part of the customer. Perhaps the higher cost of including the parking brake may be an inhibiting factor. In addition, a review of the comments suggests confusion and disagreement regarding rear disc brakes vis-a-vis front-wheel drive and the increasing application of ABS.

Only very modest expectations for rear discs are evident for light trucks and vans. Higher-performance versions of these vehicles would seem to be the most likely candidates for use of rear disc brakes.

TECH-21. What percent of North-American-produced passenger vehicles will be equipped with the following features in the years 1995 and 2000?

Features	Median Response		Interquartile Range	
	1995	2000	1995	2000
Anti-lock Brakes	30%	70%	20/40%	50/90%
Traction Control (anti-spin)	5	15	3/10	10/20

SELECTED EDITED COMMENTS

- ABS should and will be made a federal mandatory standard by 2000.
- Electronic traction control will gain acceptance at a somewhat slower rate than anti-lock braking systems.
- If government gets back into the automotive arena, ABS could become mandatory; otherwise industry will market as option for profit/value through at least 1995.
- Let us hope that the product liability shadow will not slow down ABS penetration.
- Remains to be seen if anti-spin needs throttle control to work.
- These are features which could be incorporated in active suspension relatively easily.
- These are not gimmicks, but are safety related.
- Will become a legal requirement with phase-in.
- Anti-lock brake systems will gain widespread acceptance. Once ABS is on cars, the anti-spin traction control is almost free. Acceptance of traction control systems will depend on the pricing of the option.
- As benefits of ABS become widely known by the consuming public, demand will increase dramatically. Traction control will not be desirable to a large majority of buyers if throttle override is an integral mechanism in the system.
- ABS forecast assumes government legislation for use sometime after 2005.
- ABS will be demanded by consumer (i.e., not legislated). Cost prevents more aggressive application.
- Cost and cost of repair will limit acceptance unless legislated as a safety feature.
- Cost will decrease and more customers will understand value.
- Steering control under braking conditions will continue to help expand the application of ABS.
- Technology is moving faster than anyone imagined. ABS could be across the board by the mid-1990s. Traction control benefits are just beginning to be recognized. May not be a large cost penalty beyond ABS. Great for northern one-half to two-thirds of USA.
- This technology will become the price of entry into the market.

- Traction control will start to increase rapidly following acceptance of ABS, since it is essentially a "free" feature.
- Traction control could see higher application rates if a fail-safe drive-by-wire system is developed.
- ABS will be legislated by 2000.
- ABS will be required like better bumpers, passive restraints, etc.

MANUFACTURER/SUPPLIER COMPARISON

Both OEM and supplier panelists were in agreement with the consensus median for traction control. With respect to anti-lock brakes, the supplier panelists differed from the OEM panelists with forecasts of 25% by 1995 and 60% for the year 2000.

COMPARISON OF FORECASTS: MKT–39

The Marketing panelists forecast a 25% penetration rate for anti-lock brakes by 1995 and 50% by the year 2000; traction control was forecast to be 2% by 1995 and 5% by the year 2000.

TREND FROM PREVIOUS DELPHI SURVEYS

As illustrated in the table below, projections for application of both ABS and traction control systems have decreased dramatically from Delphi IV. A review of the panelists' comments seems to indicate that cost and a lack of perceived consumer benefits may be inhibiting factors.

Features	Forecast for 1995	
	1987 Delphi IV	1989 Delphi V
Anti-lock Brakes	50%	30%
Traction Control	20	5

STRATEGIC CONSIDERATIONS

Although Delphi V expectations are diminished from those of Delphi IV, a significant utilization of anti-lock braking systems (ABS) in North-American-produced vehicles is envisioned. Some panelists think this technology will become standard during the decade of the 1990s, while others are less optimistic. A number of panelists anticipate that the federal government will mandate ABS (see TECH–22), which would have a profound impact on market penetration.

We suspect a significant factor in this forecast is the expected cost. If one considers the future system costs at $200, obviously there would be greater enthusiasm than if one sees it as an $800 feature (see MKT–41). This is an important technology that must be closely watched. Our judgment is that the Delphi V forecast will be exceeded by the domestic manufacturers because of increasing perceived consumer value.

With regard to traction control, there is still uncertainty as to how this will be accomplished: through engine power management, variations in the ABS system, or both. It is quite likely that we may see both systems ultimately employed. While there is considerably less enthusiasm for traction control than for ABS, there is still sufficient support for this technology. With both traction control and ABS, the key factor in future application will be the voice of the customer. We believe several manufacturers firmly believe customers will perceive value in ABS and are working feverishly to introduce ABS as a standard feature in high-volume product lines. They believe this could be an important differentiator in the 1990s.

TECH-22. Do you believe that anti-lock braking systems (ABS) will be required by governmental regulation in passenger cars and/or light trucks? If yes, in what year?

Vehicle	ABS by Govt. Regulation		Year ABS by Govt. Regulation	
	Yes	No	Median Response	Interquartile Range
Passenger Car	63%	37%	1998	1995/2000
Light Trucks	61	39	2000	1997/2000

SELECTED EDITED COMMENTS

- ABS is good. Present government mood is not to legislate this item on passenger cars and light trucks, but this could change.
- ABS could be accelerated if consumer groups lobby for legislation.
- Biggest benefit for anti-lock is light truck rear wheels (due to tendency for rear wheel lock-up on light trucks).
- Can't really be forecast. Depends on whether U.S. government continues to discover sanity and work on important problems they can help, e.g., productivity, education, etc.
- Competition will do it. No regulations required.
- I believe it will be phased in gradually after the year 2000.
- It will be market driven. Legislation will not be required.
- Light trucks. But not before 2000.
- Market forces will beat the government on this issue.
- Market acceptance and subsequent lower cost will generate natural demand for anti-lock braking systems.
- ABS will be required on some portion of new vehicles produced.
- ABS will be phased in, just like stricter emissions standards, passive restraints, etc.
- The industry is adopting ABS so rapidly that government rules will not be required. However, buses and heavy trucks carrying hazardous materials may become legislated.
- The marketplace will accelerate the application of the features in higher volume without the need for government regulation.
- Passenger car: introduction in 1996 with phase-in over five years. Light trucks: phase-in by 1998 over six years.

STRATEGIC CONSIDERATIONS

Approximately two-thirds of the panelists expect that government ultimately will mandate utilization of ABS systems in passenger cars and light trucks with a median year for regulation between 1998 and 2000. It appears likely that government will be following the manufacturers' widespread application of ABS. Various comments clearly illuminate some of the key issues with regard to this question. It must be kept in mind that government regulation is hard to predict with any reliability in view of the complex political pressures that abound today.

TECH-23. What percentage of North-American-produced passenger cars will have standard spares, mini-spares, or no spares in the 1995 and 2000 model years?

U.S.-Produced Cars With:	Median Response		Interquartile Range	
	1995	2000	1995	2000
Standard Spare	15%	10%	5/30%	0/20%
Mini-Spare	80	80	55/90	50/89
No Spare	5	10	0/10	2/25

SELECTED EDITED COMMENTS

- Having "no spare" is as much a marketing issue as a technical issue.
- People want the security of a spare tire, even with a current rate of 0.2% downtime for tire-related problems.
- Technology won't suppress human comfort in having a "spare." Don't expect run-flat tires to be very successful.
- Weight and space constraints and run-flat technology will obsolete spare wheels by 2000.
- Fifty percent of passenger cars will have run-flat tires by 2000.
- No spares could be considered if cost allows for puncture-proof tires.

MANUFACTURER/SUPPLIER COMPARISON

Supplier panelists forecast a considerably higher percentage of passenger cars with no spares than did the OEM panelists.

Panelist Group	Percent Vehicles with *NO* Spare			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Supplier	5%	20%	0/10%	5/40%
Manufacturer	0	6	0/5	1/20

TREND FROM PREVIOUS DELPHI SURVEYS

The following table indicates a reduction in the expectation for no spare tires in U.S.-produced passenger cars. Forecasts for the use of mini-spares has steadily increased from a Delphi I forecast of 50% for 1990 to the present Delphi forecast of 80% for 1995. At the same time, the forecasts for no spares has declined from a high of 50% (for 1990) in 1979 to the present projection of 10% (for 1995).

U.S.-Produced Cars With:	Forecast for 1990			Forecast for 1995
	1979 Delphi I	1981 Delphi II	1984 Delphi III	1989 Delphi V
Mini-Spares	50%	63%	80%	80%
Standard Spares	0	11	15	10
No Spares	50	26	5	10

STRATEGIC CONSIDERATIONS

This subject continues to be a relatively volatile question in our Delphi forecasts. Note that previous years' forecasts have varied considerably in terms of future expectations. In the most recent survey, the consensus forecast indicates the standard spare tire in passenger cars will decline in importance. The mini-spare will play a dominant role through the 1990s. However, the large interquartile range continues to indicate a considerable degree of uncertainty. In general, there is a trend of decreased optimism with regard to elimination of the spare tire. At one point in our Delphi forecasts it was anticipated that 50% of the vehicles would not have spares in 1990 and today the forecast is for only 5% without spares in 1995.

Obviously technological trends in tire development must be watched closely since there are so many ongoing programs around the world. The incentives for spare tire elimination remain strong both with regard to weight and packaging. Perhaps as confidence in "run-flat" and puncture-resistant designs improve, our panelists may become more optimistic. Obviously the implications for both the automotive and tire manufacturers are significant.

Another point of significance is that in analyzing Delphi results always consider the interquartile range (IQR). In this case the range is relatively large. The IQR is a measure of uncertainty, and those that have an extreme position really may, because of special insight, be closest to the ultimate outcome.

TECH-24. What percentage of North-American-produced passenger cars will incorporate the following tire features in the years indicated? (These categories are not necessarily mutually exclusive.)

Tire Features	Median Response		Interquartile Range	
	1995	2000	1995	2000
Puncture-Resistant	20%	30%	10/25%	20/50%
Self-Sealing	10	12	5/10	10/20
Run-Flat	5	10	2/5	5/15
Failure-Sensing Devices	2	8	1/4	4/10
"Throw-Away"	0	0	0/0	0/0
Non-Pneumatic	0	0	0/0	0/0

SELECTED EDITED COMMENTS

- Don't see much in the way of change coming!
- Cost and ride will continue to be determining factors, with further tendency toward "high performance" in appearance if not in fact. Materials breakthrough is required to make non-pneumatic tire viable.
- Electronic low-tire-pressure warning systems will start to appear in the early 1990s.
- Environment controls will influence disposal of used tires by 1995.
- Failure-sensing devices will be low-pressure warning.
- Puncture-resistant tires will eventually become mandatory by federal regulations.
- I am unaware of effective puncture-resistant technology today, nor any big pressure to develop it in the near term.
- Low rolling resistance and greater levels of uniformity will be factors in the 1990s.
- Low tire pressure sensing/warning will appear as early as 1990.
- Need to eliminate spare for weight and space needs.
- Non-pneumatic tire will appear as spare only.
- Puncture-resistant tire technology will increase in customer convenience.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in very close agreement regarding the percentage of North-American-produced passenger vehicles that will include the tire features surveyed. The only difference of opinion is for self-sealing tires and failure-sensing devices for the year 2000; manufacturer panelists forecast 10% for self-sealing tires and 6% for failure-sensing devices. The supplier panelists forecast, respectively, 15% and 10%.

TREND FROM PREVIOUS DELPHI SURVEYS

In the 1987 Delphi IV, the Technology panelists were asked a two-part question relating to tire design and the future of the "spare tire" in North-American-produced passenger vehicles by the year 2000. In response to a question eliciting opinions as to what significant tire developments could be expected in the ensuing ten-year period, a significant finding was that 100% of the panelists responded with "Performance and Design Changes." The second largest categorization was for "Construction Changes" with 71% of the respondents addressing this particular issue. Responses within the "Construction Change" category are represented in tabular form below. Note that the major construction change envisioned at that time was for run-flat tires. In the present Delphi V, run-flat tires placed third in percent of tire features incorporated by 1995.

Construction Change *(71% Total Delphi IV Technology Respondents)*	
Run-flat tires	56%
Lower cost of materials and manufacturing	11
Other Comments:	33
Airless tires.	
Cast tires.	
Molded tires (urethanes possibly).	
Larger wheel diameters, stronger sidewalls.	
Puncture proof, inner/outer tire (inner for rolling capability should outer fail), pneumatic (factory-charged tires), foam core tires, tires which due to structure and composition can be recycled into raw material for remolding.	
Composite-reinforced tires which are, for all practical purposes, puncture and blow-out proof.	
Self-sealant tires becoming an industry standard.	

In another Delphi IV question regarding the future of spare tires by the year 1995, of the group of panelists who forecast the introduction of tires that will allow the reduction or elimination of spares, the following breakdown of tire types or systems was suggested (percent of responses): run-flat tires (39%), puncture-resistant tires (23%), small inflatable spare (14%), self-sealing tires (8%), low-cost "throw-away" spare (8%), warning of failure/ sensing devices (8%).

STRATEGIC CONSIDERATIONS

Prompted by increased demand for overall performance (i.e., durability, low rolling resistance, road adhesion), technological developments in the tire area have accelerated in the past few years. Reasonably significant growth is anticipated in both puncture-resistant and run-flat tire designs through the 1990s. Furthermore, it is clear that low pressure or failure-sensing devices are expected to grow dramatically during the next decade, although penetration is forecast to remain quite small. With continued rapid growth in electronic technology, it would not be surprising to see tire-sensing devices play a more prominent role than envisioned in this forecast.

With the increased concern for fuel economy and the promise of significantly tougher corporate average fuel economy (CAFE) requirements, further reduction in tire rolling resistance would be desirable. This could tax the industry's ability to maintain an appropriate balance between important tire properties even as demands for overall quality improvements increase. The next few years promise to be rather interesting yet volatile in the light-duty tire business.

There is certainly room for creative and innovative thinking in the technology, and developments could lead to significant gains in overall tire integrity and performance.

TECH-25. What percent of North-American-produced passenger vehicles will utilize the following control placement themes in the years indicated?

Control Placement Themes	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
Conventional Instrument Panel	80%	70%	50%	57/94%	40/85%	24/80%
Stalk-Mounted Controls	40	35	35	5/85	10/85	10/85
Fingertip Reach Controls (Pods)	5	10	15	3/10	7/20	10/40
Steering-Hub-Mounted Controls	2	5	10	1/5	3/10	4/20
Some Combination of Above	20	30	35	2/100	5/100	5/100

NOTE: Because these control placement themes are not mutually exclusive, the median responses do not add to 100%.

SELECTED EDITED COMMENTS

- These are not mutually exclusive. Radio and speed control will go hub; wiper, washer, indicator go stalk; rear defroster, lights go pod!
- Control what? Speed, radio, climate, everything? There will always be conventional panels. Too many controls on a stalk is bad. Designers like them; drivers do not want them.
- Emphasis on ergonomics.
- Hub controls are a "blind alley" due to airbags.
- Percent air cushion restraint system will control steering-hub-mounted controls.
- Most vehicles will use steering hub or stalk controls for functions like speed control, windshield wiper controls, etc.
- Pods and wheel-mounted controls will be used in same vehicles, hence total of stalk, pod, and hub equal 100%.
- I believe that 100% of the cars will use "some combination of above" (i.e., conventional instrumentation and stalk controls, at minimum).
- Would like industry standardization.
- "Conventional" is changing a lot! CRTs won't make it—interaction times too long. Interaction times will dictate instrument panel design.
- Voice controls will be redundant to conventional controls.
- Agree airbags will force out hub-mounted controls.
- "Steering hub-mounted controls" assumes no airbag.
- Expect combination versus one type. Expect multi-function switches that are programmable. Expect wipers to be activated with rain sensors and lights with darkness. Switches can be manually over-rode but not prime activators.
- Nothing in hubs except horn. CRT touch screen will eventually be a yuppie, high-priced, extra feature.

- The CRT is too difficult to use: gloved hands in moving vehicles constitute a formula for disaster. We need to settle on some type of standard for our customers across vehicles.
- This area will be used for distinctiveness between cars.
- This is one area where new technology has been a major step backward; human factors, cost, and serviceability all worse than with panel-mounted controls.

MANUFACTURER/SUPPLIER COMPARISON

The differing forecasts of the manufacturer and supplier panelists are represented in the following table.

Control Placement Themes	Current Estimate		Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier	OEM	Supplier
Conventional IP	80%	85%	*	*	*	*
Pods	10	5	15	10	25	15
Steering Wheel Hub-Mounted Controls	*	*	*	*	5	10
CRT Touch Screens	0	1	1	2	2	5
Voice-Activated Controls	*	*	1	0	2	1

*No significant difference between forecasts.

STRATEGIC CONSIDERATIONS

With a growing emphasis on functionality in design, appropriate ergonomic placement consistent with attractive styling should certainly be a goal for the OEMs in the years ahead. Regardless of the system utilized, function will be placed high on the list of ergonomic criteria. The various comments for this question illustrate some of the important challenges associated with "user-friendly" and technological considerations related to automotive control placement themes. There are several areas of conflict as noted by the panelists.

One area of growing interest is the challenge between maintaining simplicity of control versus providing an increasing array of control functions. This is particularly important with increased segmentation in the marketplace. In reality, a combination of market factors, function, ergonomics, style, cost, and customer characteristics will determine control placement themes.

TECH-26. Within the following groups, what new vehicle interior developments do you foresee on North-American-produced passenger cars within the next ten years?

INSTRUMENTATION

New Instrumentation Developments	Percent of Total Responses
Heads-up display (HUD)	45.0%
Increased diagnostics, monitoring, and service warning systems	18.0
Increased navigation/trip aids	14.0
Re-emergence of analog over digital IP displays	9.0
Increase in liquid-crystal displays (LCD)	8.0
Increase in digital displays	6.5

The following interior developments received less than 5% of the total responses (in rank order):

Increased use of CRTs
Collision avoidance/obstacle detection
Flat-panel (LED) displays
Voice-activated controls

Easier-to-read graphics displays
Multiplexing
Digital/analog hybrids
Rearview TV

Developments that received three or less individual panelists' responses are listed in *Representative Responses*.

REPRESENTATIVE RESPONSES

- "Flexible" dot-matrix displays.
- "Heads-up" display redundant with instrument display; increased re-emergence of analog displays (or analog/electronic hybrid).
- Analog-type instruments will prevail together with heads-up displays in windshield and ergonomic fingertip control positioning and operation.
- Attempts at heads-up displays. Some use, but like digital displays, largely dismissed as a gimmick. "Virtual image" displays may have a place.
- Better diagnostic, oil level, oil life, tire pressure, coolant level.
- Color LCD readouts; map presentation.
- Fewer LCDs; maybe electro-luminescence; more driver feedback.
- Design variation with electronics from standard modules.
- One-hundred percent functional, no-digital lights.
- Different methods of digital systems and therefore a resurgence of same, less "overload" of readouts. Enunciation of out-of-normal-range readings only.
- Digital readout utilizing electro-luminescence and LCD.

- Easier-to-read graphics—less complexity.
- Electronic dashboards—less expensive and more adaptable to modular unit assembly.
- Electro-chromic flat displays.
- Enough is enough. No more electronic claptrap, please.
- Further use of electronic displays, including trip information and additional vehicle status information. Some navigation equipment.
- Gradual introduction of heads-up displays.
- Various warnings—road condition, object ahead, low tire, etc.
- Improved switch performance.
- Clear distance ahead readout (radar/sonar).
- Heads-up speedometer. More service warning.
- VID, holograph.
- ETAKS, reconfigurable displays.
- I doubt if any of these consumer wants will be adopted. Fewer combination controls where you have to cycle through functions to get the one you want. Simpler on-off controls reduce time and attention demand of controls.
- Increase in video-game-type displays, fully digital electronic, selective system monitoring.
- Increasing availability of satellite video map displays.
- Instrument panel adjusts with wheel (like the Ford Probe).
- Larger, clearer, more legible displays. Do not anticipate significant additional penetration of digital displays.
- Laser technology, hologram.
- LCDs. No serious penetration of HUDs.
- More computer-assist features to help the driver.
- More electronics beginning at some form of heads-up imaging.
- On-board television optional (for passenger) with VCR; voice-actuated controls.
- "Office on the road."
- Plug-in modular designs.
- Projection gauges.
- Return to analog instruments, some form of heads-up display, and use of artificial intelligence.
- Tilting/adjustable instrument cluster. Heads-up display, flexibility format displays, i.e., driver voice warnings selectable for digital or analog.
- Very little change.
- Wide acceptance of electronic displays, but with digital speed (versus analog), but other newer forms of readout for other functions.
- Wider use of optional luxury technical displays—tachometer, oil pressure, temperature (engine, inside/outside), voltage, current, miles-to-empty tank.

SEATING

New Seating Developments	Percent of Total Responses
Multi-adjustable seats	50%
Electronic memory for seat positions	27
Lightweight, thinner seats	15
Personalized, custom-contoured seats	11
Specified lumbar controls	10

Seating developments receiving multiple, but less than 10% are as follows:

Improved restraint systems/integrated belts and seats
Seat heaters
New seat fabrics/materials
Adjustable rear seats.

A substantial number of panelists commented that there will be less emphasis on appearance and more emphasis on functionality, comfort, etc.

REPRESENTATIVE RESPONSES

- "Thin," lightweight seats with comparable comfort and current, up-scale seating. Modular, removable seats.
- Adjustable support areas, more lateral support, ventilated.
- Automatic seat adjustment for each normal driver.
- Automatic location relative to steering wheel/instruments when person sits in seat.
- Broader understanding of requirements so that there are less bad seats; lighter seat structure and thinner seat structure.
- Comfortable for a human being. No more emphasis on appearance.
- Completely adjustable for weight and size on a think back-type design.
- Consumers will be heard: less puff and fluff (wasted people-space), less velcro upholstery (velour) which restricts movements, less pseudo-bucket seats (too limited).
- Ease of getting into seat from exterior, seat adjustment memory.
- Expanded use of multiple adjustments, lumbar seats.
- Greater use of memory seats. Greater use of lumbar support.
- Greater range adjustability.
- Hard/soft adjustment.
- Improvements in lateral support, new fabrics offering improved comfort and wear resistance, more use of leather-imitation substitutes.
- Inflatable bladders in molded seats.
- Innovation to accommodate additional passengers.
- Possibility of reversible (rear-facing) front passenger seats.
- Integration of seat belts with seats.
- Integral child safety seats on some cars.
- Less bulky; more controls on more series, particularly mid-series cars.

- More adjustable for support and orthopedic function, heated, more ergonomic.
- More adjustable for various size occupants, both power and manual.
- More adjustable back and cushion pressure point control. Also more safety-oriented shape and structure.
- More comfort, less glitz.
- More comfort adjustments including rear seats. Seats designed for optimum orthopedics.
- More comfort and safety via stronger seats with better torso support, and memory positioning.
- More seat controls. Increased usage of contour seats. Possibly custom-fitted seats, fitting gel-like material which will maintain form.
- More thin construction bucket seats. This trend is detrimental to passenger comfort. Better adjustability is coming.
- Multi-adjustment, ten ways.
- Multiple articulation, new suspension materials, alternate fabrics, many electronic adaptations/controls, more heating devices.
- New materials requiring less space.
- Possibly "active" change in stiffness locally. Greater safety restraint built-in. More integration with rest of interior.
- Return of the bench seat.
- Seats with many comfort adjustable features found in expensive cars or sold as high-cost option. Voice-adjust seats.
- Some all plastic.
- Specialized for individual customers. Easily changed.
- Structural seats for side impacts.
- Suspensions for seating to isolate driver from road vibration. Could involve electronics, fixed seated (no front-to-rear adjustment) requires adjustable controls for steering wheel and foot pedals.
- Thinner seats, greater use of memory sensing, and one-piece molded including upholstery.
- Wide use of more variable seating height, angle of seat, seat-back angle, and stiffness for lumbar support.
- Fourteen-way adjustment.
- New structures, more comfort and improved restraints for performance drivers.
- Six-way mechanical and electrical to accommodate differences in seating positions for men, women, young and old.

ERGONOMICS/CONTROLS

New Ergonomic/Controls Developments	Percent of Total Responses
Improved accessibility to controls†	39%
Voice-activated systems	15

†Within the *Improved accessibility to controls* category the following specific breakdown of some new developments was possible.

	Percent of Category Responses
Adjustable hand controls	13%
Adjustable pedals and belts	10
Controls moved closer to steering column	7
Stalk-mounted and fingertip reach (pods) controls	7
Steering-wheel hub-mounted controls	7

Single responses are included in *Representative Responses*.

REPRESENTATIVE RESPONSES

- Set (not redundant controls on steering wheel and IP) of truly functional controls—not pretty, small buttons which cannot be operated unless eyes are off-road or with gloves on.
- Adjustable brake and accelerator pedals, voice-activated controls.
- Aging of population will have an effect on size and placement of controls and legibility (at different focal lengths) of displays.
- All controls will be more accessible, i.e., pods, door/panels and will be centrally located—voice command for controls.
- At some point the "space" and styling effects will give way to logical, easily operated control by tactile feel and graphic symbols with no need for the driver to bend or look down.
- Audio warnings, heads-up display; pedals impossible to misapply; visibility 360 degrees.
- Both driver and passenger access to controls; some redundancy.
- Cockpit-look; wraparound IP.
- Commonization of some controls and more attention to these issues.
- Compass setting and directional plot on map/TV screen.
- Continuing development of ergonomics to support driver comfort and convenience maintaining awareness of highway conditions.
- Electronic touch pads versus switches, integrated "smart" transmission (no-shift lever), less intrusive (smaller, more controls in hub) steering wheel.
- Fewer buttons and controls, simplification of overly complex controls such as stereo.
- All automotive controls within arm's length of driver; dual controls for entertainment and comfort.
- Generally better for reach and function. Some comfort controls for rear-seat passengers.
- Hands-free cellular telephones, voice-activated option controls, enhanced vision systems.

- Human reaction time limitations should lead to improved control placement.
- More sophisticated systems. More gimmicks aimed at comfort and safety.
- More soft touch. Single-function control buttons and displays.
- Multi-function controls (LED video) with touch-to-select. Not much change. Too much styling influence.
- Personalized, flexible, occupant protection.
- Powered passive belts.
- Push button (electronic transmission) shift.
- Re-engineer interior to people needs and put styling second. I need head room, foot space, leg room, and elbow room. Stop putting controls beyond a reach location. Permit comfortable elbow resting on doors and window ledges; have full roll-down windows, vent windows, cowl vents, equally comfortable seating for all passengers. There is no car produced that treats everyone in car equally. Someone is always sitting on the hump or has no leg room. How about dial-a-shade windows to darken if you want. Don't block view of rear-seat passengers with too big front seats and headrests.
- Conductive elastomer switches.
- Return to simplified controls except on specialty cars. Easier to understand and operate controls.
- Uniformity in all makes—legislate positioning, size, shape, etc. How about legislation to force the issue!

STRATEGIC CONSIDERATIONS

Questions of this type generally prompt panelists to suggest features or developments they speculate might be available during the forecast period. Clearly, a wide range of developments are expected in vehicle interiors during the next ten years. Market factors, particularly customer-perceived value, and the move to modular construction will have a major influence on the actualization of these forecasts.

Some responses are rather interesting. For example, the support for heads-up display (HUD) in the *Instrumentation* section as a new vehicle interior development is quite surprising, particularly in view of how new and unproven this technology is. However, it should be noted that HUD's high ranking in this particular question reflects the panelists' view of the most likely new vehicle interior development. This ranking does not necessarily imply a high percent application. Also, it is often difficult to summarize or categorize many of the wide-ranging responses under a single specific heading. It is, therefore, possible some suggestions could be placed in several different or overlapping categories.

This question provoked an emotional response from a number of the panelists (note *Representative Responses*). We are not all the same in terms of sizes, shape, and what we like in vehicle interiors, controls, etc. Above all, our panelists voiced a strong emphasis on function. Of course, compromises must be made on the basis of cost, packaging, safety, style, etc., but function should increasingly receive appropriate consideration.

TECH–27. Of the North-American-produced passenger vehicles incorporating purely solid-state instrument panels, what percent will use the following technologies by the year indicated.

Instrument Panel Technologies	Percent Usage in Solid-State Instrument Panels			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Vacuum Fluorescent	25%	30%	10/50%	10/45%
Light-Emitted Diode (LED)	20	20	2/35	5/40
Liquid-Crystal Display with Lighting (LCD)	25	30	15/40	20/45
Cathode-Ray Tube (CRT)	2	5	1/5	1/10
Solid-State Equivalent of CRT	2	5	1/3	5/10
Other:				
Electro-Luminescence*				
Electro-Luminescence/Plasma*				

*Percent usage not given.

NOTE: Some vehicles will use a combination of these technologies. Therefore, the totals do not add to 100%.

SELECTED EDITED COMMENTS

- The personal computer and TV industries will significantly affect advanced display technology over next five to ten years. Therefore, above percents would significantly change if a major display breakthrough occurs.

MANUFACTURER/SUPPLIER COMPARISON

There was some difference of opinion between the manufacturer and supplier panelists regarding the percent application of the solid-state IP technologies. These differences are illustrated in the following table.

IP Technology	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
LED	*	*	5%	20%
LCD	35%	20%	*	*
CRT Equivalent	2	1	5	10

*No significant difference between forecasts.

STRATEGIC CONSIDERATIONS

Vacuum florescent and liquid-crystal (LCD) displays are expected to exhibit increases from 1995 through the year 2000. Vacuum florescent displays have long been employed in automotive instrumentation/driver information systems. However, LCDs, particularly multicolor liquid crystal, appear to be emerging as a strong competitor to vacuum florescent displays. Utilization of light emitted diode (LED) displays, a widely used technology in the consumer electronics industry, is expected to remain relatively static from 1995 through 2000. The interquartile ranges (IQR) forecast for these solid-state technologies are rather wide, indicating a considerable degree of uncertainty regarding their actual application. Awareness of uncertainty about the incorporation of technologies need not necessarily be viewed as a negative factor. This knowledge can also provide a supplier with a significant, and profitable, window of opportunity.

TECH-28. Assuming all cars will be equipped with seat belts, what percentage of North-American-produced passenger vehicles will utilize the following additional safety features for *front-seat* occupants in the years 1995 and 2000?

Additional Front-Seat Safety Features	Median Response		Interquartile Range	
	1995	2000	1995	2000
Passive-Belt Restraint Systems	50%	40%	30/65%	30/60%
Airbags				
Driver-only	20	30	10/40	12/45
Driver and front passenger	20	40	10/35	20/50
Rear-seat occupants	0	2	0/0	0/5
Airbags *plus* Other Passive Restraints	10	10	2/30	5/50

SELECTED EDITED COMMENTS

- Airbags will become temporarily mandatory until insurance companies lobby to get rid of them because of cost and insufficient protection.
- By 2000, motorized belts and airbags will be almost standard.
- Federal regulations may require driver's side passive restraints be changed to mandated airbag; active three-point belts on both sides and seat-belt law.
- Government will probably get back into passenger restraint/protection. Difficult to predict final equation.
- I think airbags will be regulated by 2000.
- Many current lap belt "passive" restraints are poorly designed and executed.
- New restraint technologies will start to replace some airbags in 2000.
- Transition from driver-only airbag to full front airbags.
- These features cost too much; customers do not perceive value.

MANUFACTURER/SUPPLIER COMPARISON

Manufacturer and supplier panelists are in very close agreement regarding the issues addressed in this question. The only meaningful difference between their forecasts is evident in the area of *Airbags plus other passive restraints*. Respective forecasts for the years 1995 and 2000 are: OEMs 5% and 10%; suppliers 10% and 20%.

TREND FROM PREVIOUS DELPHI SURVEYS

There is a very significant increase from earlier Delphi IV forecasts for the percent of North-American-produced passenger vehicles that will be equipped with airbags. In fact, the present forecast for 1995 is twice the previous Delphi. The current 1995 passive-belt restraint system forecast has also demonstrated a significant increase from the previous Delphi IV forecast of 35%.

STRATEGIC CONSIDERATIONS

Significant changes have occurred in the general attitude toward passive restraint systems since Delphi IV. Support for airbags is considerably greater with fewer negative comments. We expect important technological and ergonomic innovation in all areas of passive restraints within the next few years. Another issue of concern is the perception of how the customer views passive restraint systems. For example, in our opinion relatively few people recognize that seat belts should be used with airbags. The popular perception appears to be that the installation of airbags negates the necessity of seat-belt use. As this becomes evident to the customer, it is conceivable that a major political/legislative issue could develop and interfere with the industry's orderly implementation of passive restraint systems. In any event, we anticipate that the entire passive restraint issue will continue to be subject to a number of political and legal factors.

It is important to note that the domestic manufacturers are adjusting to a passive restraint future including airbags. Their commitment and confidence is increasing with regard to airbags, and we would not be surprised to see far greater airbag use than forecast.

TECH-29. What percent of North-American-produced passenger vehicles will utilize shoulder restraints for *rear-seat* occupants in the years 1995 and 2000?

Vehicles Utilizing:	Median Response		Interquartile Range	
	1995	2000	1995	2000
Rear-seat shoulder restraints	30%	80%	10/80%	30/100%

NOTE: Sixty-nine percent of the panelists contributing comments believe rear-seat shoulder restraints will be legislatively mandated.

SELECTED EDITED COMMENTS

- All passenger vehicles should have this now.
- Rear shoulder restraints could be legislated due to recent stories on rear-seat injuries with lap belts only.
- This could be easily implemented. Given lap-belt-only horror stories, outboard three-point rear-belts may become mandated.
- I think this will be required by law. By then numbers may be higher, e.g., 30% in 1995 and 60% by 2000.
- Legislated by 2000.
- Look for legislation. One-hundred percent on new designs, with phase in.
- Most North-American-produced passenger cars will utilize shoulder restraints by 1991 model year. Trucks will follow a few years later.
- Regulations should be expected about 1997.
- They should and will become mandatory.
- Rear shoulder restraints are too much bother to be effective.
- None. There is very little added protection.

MANUFACTURER/SUPPLIER COMPARISON

As illustrated in the following table, there was a substantial difference of opinion between the OEM and supplier panelists regarding the percentage of passenger vehicles that will utilize shoulder restraints for rear-seat occupants.

Vehicles with:	Median Response				Interquartile Range			
	Manufacturer		Supplier		Manufacturer		Supplier	
	1995	2000	1995	2000	1995	2000	1995	2000
Rear-seat restraints	50%	100%	15%	50%	20/100%	50/100%	5/40%	15/100%

STRATEGIC CONSIDERATIONS

The use of rear shoulder belts is expected to increase dramatically in the next ten years to the point where they will essentially be standard by the year 2000. From a practical standpoint, the key issue is how this will affect the interior design of vehicles. Most new vehicles are designed to facilitate inclusion of this safety feature. Consequently, any major upheaval in interior design should be avoided, because essentially all basic interior structures will be redefined before the year 2000.

TECH–30. Do you believe that impact-absorbent interior-crash protection (so-called "friendly interior") is a reasonable supplement to the standard safety features currently available? Please comment.

"Friendly Interior" as a Reasonable Supplement	Percent of Panelists
Yes	72%
No	28

DISCUSSION

The predominant (31%) opinion expressed by those panelists that responded *Yes* was that "friendly interiors" should be considered only as a supplement, not a replacement, of current standard safety features such as belts and airbags. Another significant *Yes* category of comments (17%) were related to the benefits of "friendly interiors" in cases of low-speed impact, side impact, and secondary impact. Additional benefits of friendly interiors cited by several panelists are for small children and out-of-position occupants.

The majority opinion expressed by those panelists that responded *No* was that seat belts and airbags are still necessary (34%). A significant group of panelists (22%) felt that "friendly interiors" were not technologically feasible—that there is too much variability. Another group (15%) felt that cost would be a prohibitive factor.

Other concerns expressed by smaller groups of panelists were that "friendly interiors" are not politically acceptable; they were unnecessary but will be governmentally regulated; and there were liability concerns. Several panelists also commented that "friendly interiors" were not feasible by the year 2000.

Because of the extent and diversity of comments, specific categorization is difficult. *Representative Responses* are presented to provide a greater degree of understanding of the panelists' opinions and forecasts.

YES: REPRESENTATIVE RESPONSES

- Some vehicles today are there or very close but due to liability concerns, belts, etc., will still be used.
- Failure to provide some type of impact-absorbent interior crash protection will be cited in product liability suits as negligence on the part of manufacturers.
- Additional occupant protection regardless of type of belts and/or airbags used will be required by law.
- Will be a customer dissatisfier because of reduced interior room.
- Only as a supplement, not as a primary system for impact protection. Can be particularly effective for cosmetic injury.
- Yes, but only because seat belts are not mandated. Smooth styling is a secondary benefit of "friendly interiors." Also important for side-impact protection.
- Careful placement of padding and hard interior components will be a design requirement.
- I don't think it will replace safety belts, though, unless the interior will be "claustrophobically" designed.

- Friendly interiors will always be good where style is not forced to compromise, especially on airbag vehicles where low-speed collisions are not helped by belts.
- Friendly interiors will become more widely used in the early- to mid-1990 model years due to pending legislation for vehicle side-impact protection for the occupant.
- Future developments in materials technology and engineering/styling technologies will make interiors more "friendly" in collisions.
- Very reasonable, but the cost premiums involved will mean that their use will be legislated and not voluntary.
- Will help reduce injuries from secondary impacts that occur after airbag actuation and deflation.
- With engineered plastics and metal structure analysis, contacted surfaces with or without belts can be greatly improved.
- High added protection with zero added risk. The only truly "passive" added protection.
- If perceived as important by the consumer. Current level of awareness of "friendly interiors" is very minimum.
- In some vehicle configurations, but it is very limiting for commodity vehicles.
- It has been part of car design for 20-plus years. The term and hype is silliness.
- It is often poorly done due to styling employed in interior. It should be used as much as possible but it must be durable.
- It protects occupants who refuse to protect themselves. There are too many of this type on the road!
- It's reasonable should have been done 20 years ago, but there are a lot who don't want better interiors.
- Knee bolsters on instrument pads, recessed knobs and handles, anti-lacerative windshields, padded back and front seats. Nothing exotic.
- Look at driver/passenger injury figures—much to be gained. Very logical.
- Need to cushion hard surfaces which can be impacted by occupants' heads.
- Only if the interiors are inflatable like airbags to avoid taking up the remaining interior space with cushions.
- Provides good protection near 30 mph.
- Provided the appearance doesn't remind one of a padded cell.
- Provides maximum protection in a multiple crash with lower replacement cost.
- Reasonable but unnecessary with belt use.
- Soft interior is not more expensive than hard; different occupant arrangements make universal passive belts tough to lay out. As safety concern increases, this is a good way to go. Would further reduce so-called "minor" injuries—facial, broken arms and legs, etc.
- Supplement yes—alternative no. Insurance statistics will show that friendly interiors are highly desirable.
- Supplement is key word. If everyone used seat belts, then this would be major advancement in "second impact" protection.
- Supplement only. But will be very expensive and engineering intensive.
- To the extent that buckled passengers do not contact "unfriendly" surfaces. Any other approach implies "padded cell."

NO: REPRESENTATIVE RESPONSES

- A body in a rollover or massive head-on crash is not restricted to the impact areas exclusively. Vehicle design will still require seat belt use.
- No, because I don't think you can sell safety. It must be regulated.
- Current interior design is reaching cost/benefit limit.
- How do you make glass friendly? The real answer is no.
- I don't believe this could be implemented within a serious design scenario.
- It only becomes significant without seat belts.
- Just too many variables to be practical between people and vehicle.
- Lawmakers are never satisfied with anything less than airbags. Auto companies cannot defend a "friendly interior" in an injury dispute.
- Limited because of package space intrusion and small protection afforded, related to belts or airbags.
- May be directionally correct, but airbags/passive restraints are the primary system and must be designed for occupant protection without other interior features.
- Not before 2000. Given current technologies and engineering/design constraints, it is not feasible to manage such a large amount of energy in so little space.
- Not politically acceptable as a replacement for belts or bags. Very little advantage if used with belts—adds cost with no return.
- Not technically feasible; under constraint of customer expectations for appearance, roominess, and convenience.
- Occupant cannot feel safe looking at an instrument panel, etc., that will help you during impact.
- Occupant should be restrained in seat and not hit any part of the interior. Any part that could be deformed in crash and strike occupant should be "friendly."
- Smaller vehicle trends make engineering such an interior too difficult.
- Styling and cost considerations are not what customers would desire.
- The requirement to be efficient with space is stronger than the desire to avoid the other solutions.
- They are not as safe as belts or bags.
- Too many different crash situations to protect against. Would affect interior appearance and packaging in a negative way.
- Truly friendly interiors are obtrusive, hindering occupant ingress/egress/mobility besides giving a claustrophobic feeling. There will be an increase in reducing second-impact harm by improving absorptive quality of current interior.
- Unreasonable, unnecessary, but will be required by Motor Vehicle Safety Standards!
- Too costly for manufacturing. Requires more material which is contrary to fuel economy.

STRATEGIC CONSIDERATIONS

Responses to this question suggest we can anticipate more "friendly" interiors in future vehicles. It is evident from the large number of individual responses that this question struck a chord with our panelists. The reader is urged to read these responses carefully. Although there are some sharp differences of opinion, it would appear that we can expect to see generally smoother, less intrusive interiors in future vehicles. This trend would have a significant impact on interior design and may create packaging problems.

Panelists do not view the "friendly" interior as a replacement for a restraint system, but rather as an adjunct to reduce injury. This feature will be particularly interesting to watch as style and design (interior and exterior) become a more important product differentiator. A smoother and sleeker interior may be thought of as generally consistent with the "aero" exterior look. The traditional conflicts associated with cost, function, packaging, and consumer acceptance, etc. will ensure this issue will be the subject of intense debate for at least the next ten years and perhaps beyond.

TECH-31. What new safety features do you envision will be incorporated in North-American-produced passenger vehicles by the year 2000?

New Safety Features	Percent of Panelists' Response
Collision warning/Proximity sensor	32.5%
Improved exterior/interior impact protection	17.0
Anti-lock braking systems	16.0
Radar braking	15.0
Low-cost airbag	10.0
Improved side-impact protection	10.0
Driver alert/Impaired driver monitor	9.0

Other features receiving a significant number of responses are rank-ordered as follows:

Active suspension systems
Road condition warnings
Friendly-interior surfaces
Tire safety features
Anti-lacerative glass

Improved headlights
Improved rollover protection
Traction control
Rear vision systems
Fire sensors/protection

Rear-seat restraints
Night/fog vision systems
Heads-up displays (HUD)
Four-wheel steering

In many cases it was necessary to abbreviate responses for the purpose of integrating them into representative categories. To provide a perspective of the panelists' forecast, *Representative Responses* are provided in lieu of *Selected Edited Comments*. Features cited by fewer than three panelists are in *Representative Responses*.

REPRESENTATIVE RESPONSES

- "Never-fail" tires. Instant traction increase to stop skids. Collision-avoidance systems. Improved rear and side view, visual or electronic. Side-arm control or fade away steering column. Impact resistant or tolerant exterior.
- Accident avoidance sonar/radar. Transmittal of road information from stationary sources to vehicles.
- Audio interrupt broadcast systems (similar to Europe). Road condition warnings (freeze conditions, etc.).
- Three-point power-belt systems. Enhancement in energy absorption in interior.
- Passenger compartment air filtration devices.
- Automatic seat belts. Better lights. Better tires.

- ABS (the most important safety feature since the invention of the brake), radar/infrared/ laser range (obstacle) warning devices, built-in alcohol detectors (eye movement or breath-based).
- ABS is a real benefit and will become common as cost is reduced.
- Better fire protection, rate of closure sensors.
- Better on-board systems to warn driver of impending or potential vehicle problems/ failures.
- Breakaway windshields, side-door impact strength increased, new technology for front-end collision.
- Breath analysis for convicted drunk drivers (ignition interlock).
- Collision warning systems will start to emerge. Adaptive speed control systems which maintain a minimum distance with vehicle in front of car. Collision avoidance with automatic braking could see very limited availability by the year 2000.
- Night vision improvements.
- Collision warning radar, driver doze warning, four-wheel steering (maneuverability/ stability).
- Continuous improvement in existing features. New side glass reflector concepts and plastic glazing. Visibility aids for fog/rain.
- CO sensors. Fuel cells.
- Detail improvements such as anti-lacerative windshields anticipated. Greatest increase in safety to come from proper harmonization of currently available techniques.
- Low coefficient surface (road) detectors.
- Early warning devices, i.e., for ice, approaching vehicles, etc.
- Energy-absorbing, deformable bumpers and exteriors, elastic windows (also lighter weight), friendly-interior surfaces, active suspension and anti-lock, anti-skid to help avoid collisions. All this technology is currently available. Driver training could have much more effect than all of the above.
- Hand-activated throttle or equivalent "dead-man's" switch.
- Headlight washers, airbags across board, rear shoulder straps, rollover structure improved from today, improved headlights, possibly graduated intensity brake lights.
- Heads-up displays. Voice warnings. Traffic-synchronizing cruise control.
- I believe vehicle sensing could be applied to warn you of a potential crash. I believe restraints in the rear seats will be mandatory with phase-in the years 2000 and beyond.
- Improved occupant protection. Improved vehicle crush characteristics.
- Improved steering wheels and columns.
- Improved rollover protection.
- Increased occupant protection in rear and side impacts via air cushions, structure, and safety seats. Improved visibility (better wiping, side defrosters) and rupture-proof tires.
- Intelligent vehicle-control systems of the types being considered by the Prometheus Project in Europe.
- Limp-home electronic failure mode electronic module (FMEM).
- Low-cost airbags, adjustable-mount seatbelts.
- Night and fog vision systems. Doppler radar collision warning systems.

- Non-driver-controlled emergency braking. Fog driving warning system (radar or equivalent). Failsafe blowout tire. Fire retardant—automatic, similar to Indy cars.
- None unless government regulated. Auto industry has done a lousy job on their own.
- Continuous improvement of control responsiveness.
- Occupant containment for front-seat driver and passenger and the same for rear-seat passenger in some of the more expensive vehicles.
- Pre-tensioner seatbelt system.
- Primary focus on airbags (with active belts). Icy road sensor. ABS brakes approaching standard.
- Protection from operation of vehicle by drivers under the influence of drugs or alcohol. Automatic door locks when car reaches 5 mph. Gasoline fire auto extinguisher. Limp home when electronics fail.
- Closing-speed warning and brake actuation. Fire-sensing and extinguishing features on performance cars. Anti-lacerative glass around car.
- Proximity sensors/alarms—initially on trucks for reverse (back-up) conditions. Radar (impending collision) devices with automatic braking.
- Rollover regulation on light-duty utility trucks. Current passenger car requirements on light-duty trucks. Higher crashworthiness performance for passenger cars.
- Improved control of fuel vapors. Plastic fuel tanks. Better management of the engine on frontal impacts.
- More impact-absorbent bumpers.
- Traffic condition communication to avoid congestion due to repairs, accidents, or heavy traffic.
- Tire pressure monitoring, controlled headlamp alignment.
- Warnings when rollover rates are being exceeded. Drunk-driver monitors that will not permit driver to start vehicle unless his breath test permits at driver seat.
- Radar: sound or some kind of microwave system.
- We will improve the "nut" behind the wheel.
- With push for airbags, it will be necessary to keep the occupant inside the vehicle on secondary impact/rollover (bags will encourage non-use of belts). Restraining glass will be very important given increased use of glass.
- Cross-car beams (seats may be used).
- Durability sensors or indicators that will tell when a component has exceeded its useful life.

STRATEGIC CONSIDERATIONS

Passenger car safety is a sensitive and volatile issue presently being addressed by both industry and government. Delphi panelists clearly view occupant safety as an area that will experience a dramatic increase in legislative activity (see TECH–5). In response, safety-oriented technologies appear to be developing rapidly, and a large number of these features are expected to be incorporated in passenger vehicles by the year 2000. Many of these features are already commercially available; others are expected to achieve commercialization in a relatively short period of time. However, many of the safety features suggested continue to experience significant technical problems as well as high cost. Interested parties are advised to pay close attention to both technological and political developments.

In a general sense we anticipate that public, government, and industry concerns for auto safety will increase during the next decade. A multitude of ideas are evident and progress should accelerate. It is important to read the *Representative Responses* carefully.

TECH–32. In response to mounting concerns regarding diagnostics and product liability and issues such as unintended acceleration, do you foresee the implementation of aircraft-like data recorders to record driving and operational engineering data on North-American-produced passenger vehicles? If yes, in what year do you foresee its commercial introduction?

Use of Aircraft-Like Recorders		Year Commercial Introduction	
No	Yes	Median Response	Interquartile Range
72%	28%	1995	1995/2000

NO: REPRESENTATIVE RESPONSES

- Invasion of privacy ("I see you exceeded 70 mph twenty-five times last month"). Electronic system reliability will improve to make this unnecessary. Maybe an electronic governor (RPM limiter, etc.).
- A full aircraft-like recorder is probably too costly but some diagnostic information is already being stored in non-volatile memory.
- Although product liability costs are high, they do not appear to be high enough to justify data recorders and provide cost/benefit. Also, cost/benefit is only to company, not consumer!
- Conveys a "distrust" between OEM and customer. This is unacceptable in the modern marketplace.
- Fundamentally the wrong approach. We must improve customer acceptance of products, or not prove there was pilot error.
- I hope not. Cost/benefit ratio is poor.
- Intriguing issue. Good logic for manufacturers to use; however, "invasion of privacy" issue will most likely stall implementation.
- It would take a major shift in philosophy to move to aircraft-like systems. Major hurdle: cost.
- No, not as an extra feature, but it may be available as a temporarily installable diagnostic aid for troubleshooting difficult malfunctions.
- Not on complete electronic controls—may be seen on some systems (i.e., ABS).
- Possible by 1997/1998, but not probable.
- Requires multiplex wiring and complete diagnostic capability.
- Some federal restraint on litigation will eventually be legislated to stop this madness.
- To be cost effective requires more sophisticated electronic technologies than are currently available, i.e., sensors and semiconductors.
- Concept is too complex in follow-up and operational maintenance.
- Too expensive, very limited usefulness.

- Too complex. Proof of who is driving needed. Both public and manufacturers may not see any advantage. Extra cost, no benefit unless insurance could be cheaper or manufacturers' liability cost/vehicle is less.
- Vehicle speed would be a leading candidate for variables to be recorded. Private vehicle owners would consider this an invasion of privacy.
- Too costly, need to make passenger cars more affordable. This is why there is such a great demand for light trucks.

YES: REPRESENTATIVE RESPONSES

- Already effective in engine controls and some anti-lock brake systems.
- Available today as a service feature.
- Low volume availability by 2000.
- Capability exists. Minimal cost differential since electronic control units (ECU) are already on board.
- Currently exists with airbag systems and will be expanded as litigation increases.
- Currently: electronic control modules' (ECM) recall failure modes. Currently: airbag systems with memory.
- I see data recorders, but not expensive crash-proof types. Probably electronic erasable programmable read-only memory (EEPROM).
- Improved intermittent diagnostic capability within the powertrain electronic control module may partially fulfill this concern.
- Interesting idea. Cost/benefits of such an idea would need to be analyzed.
- Many of the current engine-control systems hold diagnostic codes and, because of the complexity of the systems, most diagnostics are needed.
- Many vehicles now have engine speed, transmission gear, etc. available on diagnostic bus. All that is required is to implement a "last 30 seconds" recording loop in the computer.
- Multiplexing, which will be matured and in volume production in 1995, can be given diagnostic/data recording capability at almost no added cost.
- Slow introduction, possibly beginning with crash dynamics recording and expanding into vehicle speed, control, and location.
- There is some today, e.g., engine electronic control modules (ECMs) remember engine failure modes. Airbag systems will have memory features to remember whether the impact came before deployment.
- This will not come as a legislated item but rather as a side benefit of the electronic controls system capabilities already on-board for other reasons.
- Unfortunately, this trend will be driven by U.S. legal system. Black box most likely to be used with ABS brakes to detect speed, time, lights, etc., and with electronic throttles.
- Will be integrated into powertrain control system.
- Will probably be in the form of a semiconductor memory within existing modules. The GM C3 system had the ability to keep track of maximum speed until consumer complaints stopped it.
- With data storage literally a commodity, there will be both manufacturer and government interest.
- Yes for diagnostics; no for product liability.

- Will be on 2% of vehicles by 2015.

MANUFACTURER/SUPPLIER COMPARISON

There is an apparent diametric opposition of opinion between the manufacturer and supplier panelists regarding the issue of aircraft-like data recorders to record driving and operational engineering data. As the data presented in the following table reveals, the manufacturer panelists are clearly in favor of utilizing such a device while the supplier panelists are overwhelmingly opposed.

Panelists	Use of Aircraft-Like Recorders	
	Yes	No
OEM	60%	40%
Supplier	14	86

STRATEGIC CONSIDERATIONS

Data recorders are used on transport aircraft to provide pertinent information for post-accident investigation. Similar potential benefits are conceivable in recording automotive data, particularly in cases where it may be possible to distinguish driver error from vehicle failure as the cause of an accident. However, there are several issues affecting the feasibility of such a system in automotive applications.

In order to have widespread automotive application, an aircraft-like data recorder must be less expensive than the aircraft counterpart and the data communication from various modules to the recorder must have adequate capacity for real-time recording. Additionally, there are substantive concerns regarding privacy that must be addressed before this system could be installed on a personal passenger vehicle. Nevertheless, the fact that over one-quarter of the panelists foresee the eventual implementation of such a device warrants a careful review of the *Representative Responses* and attention to public opinion on this issue.

TECH–33. What percent of North-American-produced passenger vehicles will use materials other than conventional glass for windshields in the following years?

Vehicles Using:	Median Response		Interquartile Range	
	1995	2000	1995	2000
Alternate windshield material	0%	3%	0/3%	0/5%

Also, please specify material.

Alternate Windshield Material	Percent of Total Responses
Unspecified Plastics	29%
Polycarbonate	29
Acrylic with Coating	18
Plastic Laminates	18
Urethane	6

REPRESENTATIVE RESPONSES

- Acrylic with scratch-resistant coating.
- Acrylic/glass combination.
- Hardened plastics.
- Molded and coated polycarbonate.
- New forms of plexiglas and polycarbonates.
- Plastic laminate with variable solar radiation resistance—probably electrical activation.
- Special coatings.
- Might use an alternate material for inner layer (possibly urethane), but outer layer will need glass's abrasion resistance.
- Plastics don't and won't have adequate surface hardness.
- Some polycarbonate windshield usage may occur if the law is changed allowing it.
- The current factor limiting the use of plastic for vehicle passenger-compartment glazing is abrasives resistance. I expect that coatings will be available by the year 2000 which will permit the use of plastic glazing throughout the vehicle.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in agreement regarding the 0% forecast for windshields of North-American-built passenger vehicles that will use materials other than glass for windshields in 1995. For the year 2000, the OEM panelists forecast 5% of passenger vehicles with non-conventional glass windshields, whereas the supplier panelists forecast only 2%.

STRATEGIC CONSIDERATIONS

For a variety of reasons, the last few years have seen a growing interest in non-glass windshields. Developments, however, are occurring slowly because of a number of problems, particularly those related to cost and the difficulty of minimizing scratching on non-glass surfaces. Nonetheless, the panelists foresee some use of non-glass windshields by the year 2000. The incentives remain strong, particularly in terms of weight and safety. Consequently, developments must be watched very closely. With the progress of recent years in various plastic compounds, it would not be at all surprising to see new materials attain parity with glass.

TECH–34a. What percent of North-American-produced light-duty vehicles will be factory-equipped with styled wheels (i.e., no full covers) by the years 1995 and 2000?

Light-Duty Vehicle	Percent Equipped with Styled Wheels			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Passenger Cars	30%	50%	20/60%	30/80%
Light-Duty Trucks	10	30	10/30	15/50
Vans	20	30	10/40	20/50

SELECTED EDITED COMMENTS

- Aftermarket installation will still be the big application due to cost.
- Wheel covers will go away in the future.
- Wheel covers are added cost.

MANUFACTURER/SUPPLIER COMPARISON

There is a significant difference between the optimism of the manufacturer and supplier panelists regarding the percent of North-American-produced passenger vehicles that will be factory equipped with styled wheels.

Light-Duty Vehicle	Forecast for 1995		Forecast for 2000	
	OEM	Suppliers	OEM	Suppliers
Passenger Cars	40%	25%	60%	35%
Light-Duty Trucks	30	10	40	20
Vans	25	15	40	25

STRATEGIC CONSIDERATIONS

As is evidenced in responses to this question, significant growth is anticipated in the use of styled wheels on all types of light-duty vehicles. Obviously there are important functional aspects to this issue, but a primary concern will be the ability to be cost competitive with conventional wheel technology. Another important factor is the ability to achieve style differentiation while at the same time maintaining the full integrity of the wheel. Wheel manufacturers not fully involved with styled designs could be faced with significant shrinkage of their market.

TECH-34b. Of the styled wheels used on light-duty vehicles, what percent will be made from the following materials in the years indicated?

Materials	Percent Usage for Styled Wheels			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Steel	50%	30%	20/70%	15/60%
Aluminum	50	50	20/70	30/70
Composites*	0	20	0/0	0/30

*The following materials were suggested for composites: carbon fiber, impregnated plastics, vinyl ester/glass. Another material suggested was magnesium.

SELECTED EDITED COMMENTS

- New processes for steel and its low cost will keep steel viable. Aluminum applications will drop due to resurgence in steel.
- Steel wheels will always have corrosion problems.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in general agreement on their forecasts for 1995. For the year 2000, the manufacturer panelists forecast 35% steel, 45% aluminum; the supplier panelists for the same year forecast 30% steel and 50% aluminum.

STRATEGIC CONSIDERATIONS

A significant battle is forecast between steel and aluminum for styled wheels. Furthermore in the latter part of the 1990s, composite materials are expected to play a more prominent role. As with so many critical issues in the automotive industry, a combination of factors will determine the ultimate winner or combination of winners. Of course the customer will have a prominent place in the final decision.

Important progress is being made in most of the technologies associated with styled wheels, and we anticipate intense competition between the candidate materials. It would appear steel has a long-term basic cost advantage. However, when considered at the systems level, basic material cost may not be that important. In any event, this will be an interesting issue to watch in the next ten years.

TECH–35a. What percent of North-American-produced light-duty vehicles will utilize a water-based paint system in the following years?

Light-Duty Vehicles Utilizing:	Median Response		Interquartile Range	
	1995	2000	1995	2000
Water-Based Paint System	30%	50%	10/60%	25/90%

MANUFACTURER/SUPPLIER COMPARISON

The differing responses of the manufacturer and supplier panelists are illustrated in the following table.

Light-Duty Vehicles Utilizing:	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Water-Based Paint System	50%	20%	65%	45%

TREND FROM PREVIOUS DELPHI SURVEYS

As evidenced in the present forecast, water-based paint systems are expected to achieve substantial utilization within the next decade. In Delphi IV, a question was asked regarding the major advantages and disadvantages of this system. In order to provide a better understanding of the water-based-paint issue, that question and results are presented as follows.

It has been suggested that there will be a transition by North-American-based automobile manufacturers from solvent-based lacquers and enamels to water-based base coatings. Other than environmental considerations, what are the major advantages of this emerging paint technology and what major factors exist that could continue to inhibit its expanded use? In 1990 and 1995 what percentage of U.S.-produced vehicles will utilize a water-based base coat?

Percentage Water-Based Base Coat Used

Median Response		Interquartile Range	
1990	1995	1990	1995
10%	15%	5/15%	10/20%

Major ADVANTAGES of Water-Based Coatings	Percent of Respondents
Better appearance on metallic coatings	88%
Lower cost	68
Ease of application	22
Others:	
Less hazardous, potential styling advantages, lower brake temperatures	

Major DISADVANTAGES of Water-Base Coatings	Percent of Respondents
Capital costs to convert existing facilities	38%
Need for humidification control	38
Energy requirements	25
New technology problems	25
QC/Reliability	25
Additives required for emulsification	12

Representative Responses from Delphi IV

Advantages

- Reduces the cost of solvent.
- Lower curing temperatures equals cost savings.
- By 1995, assembly plant paint systems may be very different from today's systems.
- Difficulties of coating metallic-coated substrates, more plastics and concept of prepriming metal prior to forming could force a total change in paint systems.
- Lower insurance rates, less hazardous to employees.
- Water-base coatings would allow lower solids content to be used, resulting in improved flow and appearance.
- Lower brake temperatures will be breakthrough for lower cost plastic panel material to be used.

Disadvantages

- Energy requirement. Reactive systems with recycling of volatiles is likely long-term winner.
- Inability of plant facilities to control temperature and humidity. Again, it depends on technology development, e.g., competitive materials, new processes, etc.
- Heat required for evaporating water and additives required for emulsification.
- Pain installations that exist today are costly and incompatible with water-base technology.

Discussion from Delphi IV

It was forecast in Delphi IV that 10% of U.S.-produced vehicles would utilize a water-based base coat in 1990 and 15% in 1995. The interquartile ranges for both the median values are very tight, indicating a good consensus. A majority of the respondents felt that a better appearance on metallic coating was a major advantage of water-based coatings. Lower cost and ease of application were cited as other principal advantages. The major disadvantages are basically the problems generally associated with the implementation of a new technology and the capital costs necessary to convert existing facilities to accommodate the new technology.

The groupings of responses for both advantages and disadvantages are the result of integrating the various responses of the panelists. Therefore, in order to provide as much insight as possible into the thoughts of the panelists, "Representative Responses" are presented above in lieu of "Selected Edited Comments."

STRATEGIC CONSIDERATIONS

Significant growth is envisioned in water-based paint systems. This in part is prompted by increasingly stringent environmental regulations in industry paint shops as well as demands for greater variety of colors and quality of painting. Considering the enormous expense of paint facilities and aftermarket paint shops, the implications can be rather substantial in terms of overall system cost. Additionally, there are other basic paint systems that could achieve commercialization in the next ten years which could challenge the forecasts presented in this question. This is a rapidly evolving area. Careful attention should be given to water-based and other emerging paint technologies.

TECH–35b. What new paint finish technologies do you foresee will be introduced by the year 2000?

Paint Technologies by 2000	Percent of Responses
Mold-In Color	15%
Paint Film Coatings	15
Decrease in Cure Temperature	15
Base Coat/Clear Coat	15
Other (included in *Representative Responses*)	40

REPRESENTATIVE RESPONSES

- Changeable colors.
- Film coatings rather than spray-on. It will be more like Saran Wrap.
- In-mold "primer" for exterior plastic panels, requiring only top coat. One-coat-base/clear-coat technology (base and clear separate before curing).
- Low-temperature cure E-coat to accommodate plastics elimination of E-coat in assembly plants through use of pre-primed base materials. Base coats and clear coats with improved adhesion, chip resistance, and hiding power.
- Lower cure temperatures, lower toxicities (no melamines or isocyanates), coil-coated steel for hoods and deck lids.
- More treated materials left unpainted.

STRATEGIC CONSIDERATIONS

Following up on the previous question, various concepts in paint technology are being considered by the industry. They range from the use of mold-in color for plastics to different systems for base-coat clear-coat. This is clearly an area with the potential for innovation. For example, off-line painting with acceptable color match could be an exciting future development. Obviously, with increased usage of plastics, there is some concern about higher bake oven temperatures as well as ongoing concerns regarding environmental aspects of the paint operation. These will certainly be key factors in the new paint technologies that could emerge. Also, the customers' demand for quality and variety in automotive products will stimulate the development of new processes.

TECH-36. Forecast the material content, *in pounds*, and the total curb weight (dry, unloaded) for the average North-American-produced passenger car for model years 1995 and 2000.

Materials	Median Response		Interquartile Range	
	1995	2000	1995	2000
STEEL				
Low Carbon Steel	1350	1200	1250/1400	1000/1300
HSLA Steel	250	275	230/275	245/300
Stainless Stee	32	35	30/40	30/50
Other Steels	50	50	50/55	40/51
TOTAL	1682	1560	1600/1705	1400/1625
CAST IRON	400	350	400/440	300/400
ALUMINUM				
Castings	130	150	120/150	135/200
Wrought Aluminum	35	50	25/50	23/65
TOTAL	165	200	150/175	160/220
PLASTICS				
Unreinforced (no fiber content)	90	90	80/100	80/120
Reinforced (<40% fiber content)	80	120	80/100	95/130
Structural Reinforced Composites (>40% fiber)	50	60	30/60	50/90
TOTAL	220	270	240/250	270/325
COPPER	25	20	20/25	20/25
ZINC (including coatings)	20	20	16/25	15/25
MAGNESIUM	2	2	1/4	1/8
GLASS	88	86	84/90	80/100
CERAMICS	2	5	2/5	3/10
POWDERED METALS	28	30	25/30	25/35
RUBBER				
Tires (include spare)	100	97	100/110	90/110
All Other Rubber	20	28	20/30	20/35
TOTAL	120	125	130/135	125/135
TOTAL All OTHER (includes lead, cloth, insulation, carpets, foam, fluids)	280	275	270/285	250/285
TOTAL VEHICLE	3032	2943	3000/3100	2800/2975

SELECTED EDITED COMMENTS

- Cast iron will be replaced by aluminum, ceramics, and reinforced plastics. Thermoplastic elastomers (TPEs) will displace traditional rubbers in non-tire uses in some areas.
- Copper will continue to diminish as new magnet materials and multiplexing come into use.
- There will be a significant increase in composites for both structural and functional components.
- Powertrain composites will slowly increase. Aluminum/plastic, etc. will be used in similar quantities as today but not necessarily on same components.
- Trending downward on rubber tires (eliminate spare). Glazing other than SiO_2 will start making headway as we approach 2000, but increased exposed greenhouse areas will keep glass content constant.
- Average vehicles are going to increase in weight until the mid-1990s, then we'll be forced into a size/weight reduction mode.
- Car curb weight will remain same but CAD will help weight reduction significantly.
- Composites are still a hard sell internally to most of the domestic manufacturers.
- Expected total vehicle weight will remain fairly constant through the year 2000 based on present fuel economy regulations and vehicle sizes.
- Increased use of structural composites will be primarily responsible for downward trend in total vehicle weight.
- Increased usage of structural composites will occur in body and chassis where their unique properties will be advantageous for vehicle performance requirements. This increased usage of composites will be of some environmental concern during production (toxic waste handling) and recycling.
- More efficient glazing materials. Plastics will drive efficiency progress in SiO_2.
- Glass area will increase significantly, abetted by solar reflector/screening technology to reduce greenhouse effects. Structural composites will grow very slowly because of lack of cost-effective processing techniques, inability to adequately inspect by non-destructive methods and inability to repair in the field. Reinforced materials with lower fiber loadings will be increased as high temperature polymers come into more use under the hood. I included SMC in my estimates of "reinforced <40% fiber" because the body panel applications are not really structured but only cosmetic. They really do have more than 40% fiber/mineral reinforcement, however. I think RIM and thermoplastics will restrain rapid growth of SMC parts.
- The power roll is on again. Bigger engines, transmissions, etc. Fuel availability/price may change this direction.

TREND FROM PREVIOUS DELPHI SURVEYS

Materials	Forecast for 1990				Forecast for 1995	
	1979 Delphi I	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
Steel	1400 lbs	1300 lbs	1400 lbs	1525 lbs	1360 lbs	1682 lbs
Aluminum	200	200	137	155	186	165
Plastics	300	300	225	243	295	220
Cast Iron	250	250	270	375	300	400
Other	365	200	387	430	428	565
TOTAL	2515 lbs	2250 lbs	2419 lbs	2728 lbs	2569 lbs	3032 lbs

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in general accord on their materials forecasts.

STRATEGIC CONSIDERATIONS

What is remarkable about the current Delphi forecast is the substantial increase (compared to previous Delphis) in total dry-curb weight for the years 1995 through 2000. The Delphi V 1995 forecast of 3049 lbs is a significant increase over the previous Delphi IV projection of 2569 lbs. The OPEC-precipitated oil shock of the early 1970s and federal regulatory activity combined to stimulate efforts on the part of the domestic vehicle manufacturers to downsize and increase the fuel economy of the average passenger vehicle. However, subsequent market factors have had a significant influence on vehicle size and, therefore, average vehicle weight. Adjusted for inflation, petroleum prices remain considerably below previous forecasts. The American consumer has indicated a continued desire for high performance and larger automobiles. Additionally, continuing improvements in powertrain efficiency, lower-rolling-resistance tires, improved aerodynamics, new materials, and advanced-vehicle design techniques have contributed to improved fuel economy without a significant change in average vehicle occupant and luggage capacity.

A notable change is evident in the area of steels and plastics. In Delphi IV it was forecast that by 1995, steels would represent 1360 lbs and plastics 295 lbs of the average weight of a North-American-produced passenger car. At that time the interquartile range for steel was reasonably tight, whereas the IQR for plastics was rather broad. This indicated a good consensus for steel but a considerable degree of uncertainty regarding the application of plastics. While it is clear that there will be an increasing utilization of plastics through the year 2000, Delphi V forecasts indicate that the competition between steel and plastics will continue to be intense.

Other automotive material forecasts demonstrating significant change from Delphi IV are aluminum and cast iron. Aluminum use is expected to grow but not to the extent of earlier forecasts. Furthermore, cast iron is forecast to decrease but not as much as forecast in Delphi IV.

Expectations for content of other materials, such as glass, magnesium, ceramics, and powdered metals are consistent with previous forecasts. Materials technology for automotive applications will continue to be an area of continuing evolution and development and, in some cases, revolution. All materials are benefiting from significant improvements in design and manufacturing. Also, the industry appears to be experiencing a substantive re-evaluation of traditional technologies. One important example is steel, which has undergone a modest rebirth as the joint efforts of the steel and auto industries have led to considerable improvements in cost-effective processing. At the same time other materials, such as plastics, are experiencing the effects of increasing environmental concerns, processing challenges, and cost issues. Emerging process and product technologies for both conventional and new materials are advancing at such a rapid pace that a clear vision of the future is difficult to obtain. This situation presents considerable challenges and opportunities for the vehicle manufacturer, component supplier, and materials supplier and ensures a most interesting and complex future for all automotive materials.

Recent concerns regarding fuel economy (possibly increased CAFE standards) and emissions could cause a resurgence of interest in lightweight materials, which would enable maintenance of vehicle size while permitting weight reduction.

TECH-37. What is your forecast for the material mix of steel, aluminum, and plastic-reinforced composites used in frame/structural members in integral body/frame and in space-frame designs for North-American-produced vehicles in the following years?

Material Mix	Median Response		Interquartile Range	
	1995	2000	1995	2000
INTEGRAL BODY/FRAME				
Steel	90%	85%	90/95%	85/90%
Aluminum	5	7	4/6	4/7
Composites	5	8	2/5	5/10
SPACE FRAME				
Steel	85%	75%	80/90%	70/84%
Aluminum	5	10	5/8	6/12
Composites	8	14	5/10	8/20

SELECTED EDITED COMMENTS

- As long as steel is least expensive and manufacturers have steel processing equipment in place, steel wins.
- Cost will stand in the way of this trend. If material and manufacturing costs come down, however, expect an accelerated shift to aluminum and composites.
- Steel will decrease substantially while plastics will increase. Aluminum should stay about the same.
- Steel will remain dominant. Some increase in plastic to achieve appearance change at low investment.
- Use of aluminum will increase only moderately, and composites will increase moderately because of high costs in 1995. However, costs should come down as use increases. Use in 2000 may be significant due to weight saved and noise, vibration, and harshness advantages.
- We're so close to 1995 that a major change from current percentages seems unlikely.
- Because of lack of cost-effective processing technology, lack of field repair knowledge and infrastructure, and lack of nondestructive testing capability both in plant and in field, composite frame use will grow only very slowly. Present aluminum price run-up is artificial. Price will come down and tubular space-frame use will increase.
- Cost is definitely a factor, but extensive testing is required to make the changes to aluminum and composites along with changes in fastening methods, which pushes the use of these materials out beyond the year 2000 for integral body/frames.
- Even though costs on aluminum and composites will come down, increased usage will slow cost reduction (particularly composites) due to application learning curve.
- Steel will continue to be the material of choice due to cost and material property advantages. Increased use of structural composites will occur, especially in space frames.

MANUFACTURER/SUPPLIER COMPARISON

For integral body/frame material mix, the manufacturer and supplier panelists are in agreement for 1995. For the year 2000, the supplier panelists are in agreement with the consensus medians presented in the data table, whereas the manufacturers forecast steel at 90%, aluminum at 5%, and composites at 5%.

With regard to the material mix of space-frame designs, the manufacturer and supplier panelists are in agreement with each other and the median consensus for 1995. Both groups diverged from the median forecasts for the year 2000. The OEM panelists expect the material mix for this design to be: steel 80%, aluminum 7%, and composites 13%. The supplier panelists are expecting only 70% for steel, 10% for aluminum, and 15% for composites. The interquartile ranges for both groups represent a good degree of consensus.

TREND FROM PREVIOUS DELPHI SURVEYS

The 1990 material mix forecast in the 1987 Delphi IV is identical with the 1995 material mix forecast in this present Delphi. In Delphi IV the material mix projected for 1995 was: steel 80%, aluminum 10%, and composites 10%.

STRATEGIC CONSIDERATIONS

Steel is expected to remain the dominant material in future automotive structural applications in both integral body/frame and space-frames through the year 2000. In fact, in comparison to Delphi IV, steel is expected to play a stronger role in both designs. Still, there is considerable enthusiasm for both aluminum and composite materials in these future structures. We believe the modest downgrading of expectations for aluminum and composites is related to a number of factors, including shifts in commodity pricing, difficult processing problems, particularly with composites, and recent progress with steel technologies. Considering the significant cost advantage of steel, it will not easily be displaced by other new materials. However, considering the fast pace of technological development in all of these materials, we anticipate a volatile future. It would be somewhat surprising if the forecast for both aluminum and composite materials in frames is achieved, considering the relatively close proximity of 1995. Furthermore, with the recent aggressive action on the part of the steel industry and the automotive-steel industry partnership, it is likely that steel will continue to be a fast-moving target for competitive materials. This is an interesting and important area of materials technology and it must be watched closely.

TECH-38. Consider the following list of automotive exterior components and indicate the percentage of each likely to be produced in 1995 and 2000 in North America from either steel or plastics (consider all forms).

Automotive Components	Median Response		Interquartile Range	
	1995	2000	1995	2000
STEEL				
Hood (exterior)	90%	85%	90/94%	80/87%
Roof	95	95	95/98	90/95
Doors	95	90	90/95	85/90
Rear Deck	90	85	90/95	80/90
Front Fenders	90	80	90/95	80/89
Rear Quarter Panels	95	90	90/95	85/95
PLASTICS				
Hood (exterior)	10%	15%	5/10%	12/20%
Roof	5	5	2/5	5/10
Doors	5	10	5/10	10/15
Rear Deck	10	15	6/10	10/20
Front Fenders	10	20	5/10	11/20
Rear Quarter Panels	5	10	5/10	5/15

SELECTED EDITED COMMENTS

- Bolt-on panels such as hood, rear deck, doors, and fenders are the most suitable for composites. Rear quarter and roof are traditionally integral with the body (welded) and are not as easily substituted with composites. The primary factors for selection of steel versus plastics are cost (piece-cost and investment) and styling (flexibility).
- Cost of plastics will remain a major factor. The industry is looking for a material costing under $1.00/pound. Unfortunately, most plastics in this price range cannot withstand paint/electro-coat oven temperatures. Until then, steel is king.
- Crash and other vehicle energy management requirements will not allow more rapid incorporation of plastics in the front-end construction, particularly because the vehicle must crush. This dictates continued use of sheet-metal substructure which may even offset any cosmetic benefit offered by plastics. In addition, capital expenditures for plastic body panels are not competitive with metal at greater than niche volumes (50,000 plus).
- Degradable plastic panels will be increasingly used for competitive reasons.
- Expect dramatic improvements in surface quality of plastics. Usage will increase dramatically by 2000.
- Expect increased use of recycled aluminum (e.g., cans) for hood and deck lids and composites in doors, fenders, and quarters.
- Fenders and rear deck are best opportunity for plastics.
- Plastics will be used on highly styled cars that must have frequent model change.
- Safety issue will force the use of steel in areas such as roof and doors.
- Steel industry has responded well to needs for high-quality coated steels. Costs favor steel, given adequate quality.

- Steel will continue to dominate in volume applications, but plastic will become increasingly attractive in niche and low-volume applications.
- Structural requirements of quarter panels reduce usage potential until space-frame designs accommodate them. Most plastic panel use will be in trucks and vans, except for fenders. In roof, safety and size problems will keep plastics out. Improved steel stamping processes, lower tool costs, and better designs will keep steel dominant in rear decks in autos. Truck and van hoods will go to plastics because of short-run length economic advantages.
- Expect steel to be surprisingly competitive from cost and capital standpoint.
- Must use degradable plastic.
- Plastic panels may not be used at all by year 2000 if recycling/environmental issue is not resolved. We expect to see a few aluminum body panels (hoods) by 1995.
- Rollover safety will keep plastics out of roofs. Structural needs will keep plastics out of quarter panels except for small ones in special bird-cage cars.
- Safety/crashworthy factors will influence freedom of choice.
- Until coating temperatures are below 300°F and/or space-frames are accepted, plastics will make slow penetration.

MANUFACTURER/SUPPLIER COMPARISON

With two minor exceptions, the manufacturer and supplier panelists were in nearly complete agreement on the percentage of automotive exterior components likely to be produced from either steel or plastic in both years 1995 and 2000. The two component forecasts for year 2000 are as follows: OEM panelists forecast rear decks to be 90% steel by the year 2000, the supplier panelists were 5% less at 85% steel; OEMs forecast front fenders at 85% by year 2000, suppliers forecast 90% steel.

TREND FROM PREVIOUS DELPHI SURVEYS

As is evident in the trends table below, there is a significant increase in forecasts for percent of steel used in the automotive exterior components surveyed. This increase is, obviously, at the expense of plastics.

Automotive Components	Forecast for 1995			
	Steel		Plastics	
	1987 Delphi IV	1989 Delphi V	1987 Delphi IV	1989 Delphi V
Hood	70%	90%	30%	10%
Roof	85	95	15	5
Doors	75	95	25	5
Rear Deck	60	90	40	10
Front Fenders	67	90	33	10
Rear Quarter Panels	70	95	30	5

STRATEGIC CONSIDERATIONS

Because of the continuing significant interest in a variety of polymers in automotive exterior components, this question follows a similar one in Delphi IV. In general, we observe a dramatic decrease in expectations for the use of plastics compared to the prior Delphi. As is evident in the Delphi IV/Delphi V trend table for 1995, there is no question that plastics will play a more prominent role in the future, but the rate of conversion in essentially all exterior components is far less than previously anticipated. It is obvious steel will remain the dominant material through the 1990s, in part due to the technological progress made in fabricating cost-effective components from steel. While steel has a fundamental advantage of low cost, plastics possess numerous positive attributes such as dent resistance and corrosion protection. By no means is this a simple issue, and we expect considerable competition between plastics and steel during the next decade. Even with the decreased percentages expected for plastics when compared to prior Delphis, the increased use of plastics in the vehicle exterior is significant.

It is evident the automotive manufacturers shifted their philosophy with regard to plastics. They were originally on a course to solve management problems in steel processing with the substitution of plastics. Today, they are taking a more realistic approach, which emphasizes the solution of systems/management-related problems in conventional materials and to use this new level as the basis for comparison with alternative materials. All material decisions must be based on comparisons with equivalent world-class state-of-the-art processing.

A continuing uncertainty with respect to exterior materials is the voice of the customer. Presently the consumer does not appear to place particular value on any material in the vehicle exterior. This could, however, change rather quickly and obviously skew the material picture rather dramatically. For example, if the customer is willing to pay a premium, such as $100 for ding-free doors, that marketing consideration could have a significant impact on the materials decision.

TECH–39a. What percentage of light-duty vehicle engines produced in the U.S. in 1995 and 2000 will utilize aluminum cylinder heads and/or blocks?

Light-Duty Vehicle Engines Aluminum Application	Median Response		Interquartile Range	
	1995	2000	1995	2000
Aluminum Heads	50%	70%	50/60%	65/80%
Aluminum Blocks	6	12	5/10	10/20

SELECTED EDITED COMMENTS

- Aluminum price will be key factor, plus use of lost-foam casting techniques.
- Anticipate that more efficient design of iron heads and blocks will make weight reduction/change in cost for aluminum unattractive.
- Cost of aluminum will drive down volume usage.
- Thin-wall iron casting could make a major cylinder head inroad in place of aluminum. Same is true for blocks. Otherwise aluminum blocks will gain more favor.
- We're woefully behind Europe and Japan. Who but Russians and Americans use crude cast iron heads?
- Aluminum heads will be universal in double overhead cam (DOHC) engine applications. Aluminum blocks will see increased application in large FWD vehicles to improve weight distribution.
- Gains will be made in block design to reduce weight. Expect to see plastic blocks to some degree by 2000.
- Need the weight reduction. Imports will use more aluminum than domestics.
- New, small V-8s will use aluminum blocks for weight/fuel economy reasons.
- Will depend on continuous improvement in aluminum casting. If no improvement, numbers will be lower. If important improvements, could be near 100% aluminum by 2000.
- Fifty percent aluminum heads and 40% blocks by 2000 will represent the approximate limit. No substantial increases beyond this is likely.

MANUFACTURER/SUPPLIER COMPARISON

The two groups of panelists are in agreement on forecasts for aluminum heads and blocks in 1995 and 2000.

TREND FROM PREVIOUS DELPHI SURVEYS

From the 1981 Delphi II survey to the 1984 Delphi III, the 1990 forecast for aluminum heads in North-American-produced passenger cars dropped 20 percentage points. This rose to a Delphi IV forecast of 35% in 1990 and 60% in 1995. The present Delphi V 1995 forecast is 50%. The trend for aluminum blocks during this same period follows the trend pattern for heads.

Light-Duty Engines	Forecast for 1990			Forecast for 1995	
	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
Aluminum Heads	50%	30%	35%	60%	50%
Aluminum Blocks	15	10	10	15	6

STRATEGIC CONSIDERATIONS

On a percentage basis a significant increase was forecast by the panelists for the use of aluminum heads and blocks between the years 1995 and 2000. However, aluminum heads are expected to be far more prominent than aluminum blocks during the next decade. The growth in application of aluminum heads is generally consistent with the trends observed in the prior forecast, whereas there has been a modest decrease in expectations for aluminum in cylinder blocks. The recent volatility in commodity prices, particularly of aluminum, may be dampening expectations. This issue was raised rather specifically in the comments. Furthermore, it is evident that the threat from aluminum has prompted significant improvements in cast iron technology with the development of higher-quality thin-wall casting techniques.

With the high rate of engine redesign during the next ten years, alternative materials for both blocks and heads should be carefully examined. In a rather stable powertrain environment, change should be expected to occur slowly. However, with a fast rate of change, a shift to new materials could suddenly accelerate. There are some novel approaches being evaluated in both cylinder block and head technology that may prompt consideration of materials that are presently receiving little consideration. As noted earlier, renewed emphasis on fuel economy and tighter emissions standards could have significant impact on this area as well, particularly as it relates to vehicle weight.

TECH-39b. Of the aluminum blocks forecast in TECH-39a, please forecast the percentage that will be unsleeved and the percentage that will be sleeved.

Aluminum Blocks	Median Response		Interquartile Range	
	1995	2000	1995	2000
Unsleeved	5%	15%	5/10%	10/20%
Sleeved	95	85	90/95	75/90
TOTAL	100%	100%		

Also, please indicate the sleeve material you believe will be used and percent application.

Sleeving Material	Percent Application
Iron	65%
Ceramics	22
Aluminum	13

SELECTED EDITED COMMENTS

- Sleeving material process percentages will vary for 1995 and 2000. More than two types are likely.
- Slip-fit free-standing liner is poor approach as currently done.
- So much technology; so few paying customers!
- "Unsleeved" includes Porsche/Mercedes-like "silicon-rich" core surfaces.
- Cautious movement toward unsleeved!
- Long-term objective is unsleeved. Takes time, though!
- The unsleeved works well. The previous failures have auto companies frightened—implementation will probably be gradual.
- Unsleeved not robust to dirt, poor oil, etc.
- Unsleeved blocks will remain in use in high-priced European vehicles.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in general agreement with each other and the consensus median percentages presented.

TREND FROM PREVIOUS DELPHI SURVEYS

In Delphi IV the panelists forecast that in 1995, 10% of aluminum blocks would be unsleeved. Of those engines that would be sleeved in 1995, cast iron was forecast to be the material used in 80% of the engines.

STRATEGIC CONSIDERATIONS

As evidenced by their low expectations for both 1995 and 2000, Technology panelists view the use of unsleeved aluminum engines with a degree of suspicion. This is undoubtedly due in part to the legacy of unsatisfactory applications a few years ago. However, with the continued impressive developments around the world suggesting there are no inherent problems with today's unsleeved designs, the modest expectations are quite surprising. The North American industry must have absolute proof in hand before any significant shift occurs to unsleeved designs. This is consistent with increased emphasis on quality and substantially longer warranty periods which cause manufacturers to be cautious about accepting uncertain technologies.

The candidate materials for cylinder sleeves continue to emphasize iron-based alloys. However, there is growing enthusiasm for both ceramics and special aluminum alloys.

TECH–40. What percentage of North-American-produced cars and light-duty vehicles will utilize the following polymer-based engine components by the year 2000?

Polymer-Based Engine Components	Percent Usage by the Year 2000	
	Median Response	Interquartile Range
Intake Manifold	15%	10/20%
Oil Pan	20	10/30
Valve Covers	30	20/50
Connecting Rods	0	0/1
Piston Skirts	0	0/1
Rocker Arms	0	0/1

**Other* suggestions for polymer-based engine components and percent application are: timing belt cover 27%; water pump housing 23%; fuel rails 15%; pulleys 15%; thermostat housing 12%; throttle bodies 4%; oil pump 4%.

SELECTED EDITED COMMENTS

- Cost will limit application.
- Not cost effective! Oil sealing (and fire) risks!
- Not likely a big change in moving parts. Big opportunities in non-moving parts.
- Plastic water pump and oil pump impellers will dominate. Plastic timing belt covers will be used. More plastics in transmission parts. Plastic radiator end-caps will dominate. Plastic throttle bodies will be used.
- There is too much risk in polymers for guys who still regret the passing of L-heads, and who have tooled up for new rocker arm push-rod engines for next year.
- Plastic oil pans only justified for exotic deep drawn shapes where steel is unusable.
- Plastics offer much more than cost savings—sound reduction, weight savings, low thermal conductivity. These benefits won't be ignored.
- Polymers will see more use, but limited where fatigue becomes a concern.

MANUFACTURER/SUPPLIER COMPARISON

As illustrated in the following table, the manufacturer and supplier panelists differed somewhat in their forecasts for polymer-based engine components by the year 2000.

Polymer-Based Engine Components	Forecast for 2000	
	OEM	Supplier
Intake Manifold	15%	10%
Oil Pan	15	20
Valve Covers	30	35

TREND FROM PREVIOUS DELPHI SURVEYS

The following table represents the percentage of polymer-based engine components forecast by Delphi IV panelists for the year 1995.

Polymer-Based Engine Components	Delphi IV Forecast Usage by 1995	
	Median Response	Interquartile Range
Intake Manifold	10%	5/15%
Oil Pan	10	5/15
Valve Covers	10	5/20
Connecting Rods	0	0/1
Piston Skirts	0	0/1
Rocker Arms	0	0/1

STRATEGIC CONSIDERATIONS

Modest growth in the use of polymers is anticipated in several key engine components, in particular the intake manifold, oil pan, and valve covers. However, other components such as connecting rods, piston skirts, and rocker arms received little support. In addition, a wide variety of primarily non-structural components were suggested by panelists as candidates for polymer-based construction. Generally the trend forecast for the year 2000 is in agreement with the Delphi IV forecast for 1995.

The interquartile ranges are quite wide, suggesting a high level of uncertainty. There is no question, however, that polymer-based components are expected to play a prominent role in the engines of the future. As we have observed in most areas of the vehicle, competition can be expected to be intense between candidate materials. This is certainly true of a number of basic engine components. It appears that suppliers of traditional material-based components are vulnerable to new technology.

TECH–41a. What percent of spark-ignited and diesel engines in North-American-produced passenger vehicles will use the following ceramic engine components in the years 1995 and 2000?

Ceramic Engine Components	Percent Usage in Spark-Ignited Engines			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Valve train components (includes valves, inserts, guide seats, tappets, cam, etc.)	2%	10%	1/5%	5/15%
Exhaust manifold/port liner	3	10	0/5	3/15
Turbocharger turbine/rotor	5	15	2/15	5/40
Piston crown	2	8	0/10	2/15
Piston rings, coating	0	0	0/1	0/10
Seals	2	10	0/5	2/20
	Percent Usage in Diesel Engines			
Valve train components (incl. valves, inserts, guide seats, tappets, cam, etc.)	5%	10%	2/10	6/20
Port liners	5	10	1/10	1/25
Turbocharger turbine/rotor	5	15	2/15	5/40
Piston crown	2	8	0/10	2/15
Piston rings (coating)	0	0	0/1	0/10
Combustion chamber (incl. prechamber)	2	10	0/5	2/20
Seals	1	5	0/5	1/20

SELECTED EDITED COMMENTS

- All current water pump seals use ceramic sealing elements.
- Can't estimate specifics but would expect some limited usage as ceramics improve emissions and/or durability and maybe efficiency.
- Ceramic coatings will likely play an important role in items such as combustion chambers, etc. Valve train components are most likely to be monolithic ceramics and lead the way for ceramic usage in both spark-ignited and diesel engines.
- Ceramics will be used as molding techniques improve and the control of dissimilar materials are perfected.
- Don't believe ceramics will catch on even though there is a need/want. Cost continues to be unsolved obstacle.
- In general, ceramics will continue to have low penetration, approximately 5%.
- Not applicable since diesel market is 0% for passenger cars.
- The reliability risk is high and the piece-cost is high.
- Three reasons for ceramics application: (1) friction reduction to increase fuel economy; (2) weight reduction; and (3) heat-transfer reduction (insulation).
- One-hundred percent (of turbos) if EPA standards change.
- Ceramics used in diesel and spark-ignited engine bearings and wear parts.

- Ceramic diesel engine injector nozzles in 2000; cooled nozzles have a greater potential (50% in 2000).

MANUFACTURER/SUPPLIER COMPARISON

Percentages of ceramic engine components which demonstrated a significant difference of opinion between the OEM and supplier panelists are as follows.

Ceramic Components	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Exhaust Manifold	*	*	10%	6%
Turbocharger Turbine/Rotor	*	*	5	8
Piston Crown	0%	*	*	2
Seals	2	1	6	3

*No significant difference between forecasts.

TREND FROM PREVIOUS DELPHI SURVEYS

In the 1984 Delphi III the following question was asked: "When will ceramic engine components be used commercially, not just experimentally, and what three parts will be produced first?" In the 1987 Delphi IV, the following question was asked: "Which ceramic engine components will be used commercially (30,000+ units), not just experimentally, by 1995 in spark-ignited engines?" Despite the difference in the wording of the two questions, the top five components listed in Delphi IV were essentially the same top components listed in Delphi III. With the addition of seals, these are the same components that are surveyed for percentage penetration in this current Delphi.

STRATEGIC CONSIDERATIONS

The optimism for ceramic materials in engine components continues, although somewhat tempered from just a few years ago. However, the magnitude of the individual forecasts from 1995 through the year 2000 suggest that ceramics could play a minor, but still important, role in a variety of key engine components. With successful production experience it is conceivable that ceramic use could expand rapidly beyond this forecast. One must keep in mind that there are significant differences between spark-ignited and diesel engines in terms of the basic combustion process. The insulating qualities of ceramics in the diesel engine combustion chamber are highly advantageous in terms of diesel combustion. Just the opposite is true with the spark-ignition engine, since the higher gas temperatures due to reduced heat transfer could increase engine octane requirement.

Manufacturing considerations are still extremely important and a key factor limiting a number of applications. It is conceivable that tightening emissions and fuel economy standards will accelerate efforts. For example, ceramic exhaust port liners reduce in-engine but post-combustion chamber heat transfer and accelerate ignition of the catalytic reactor.

It also appears clear that the concept expressed a few years ago of an essentially "ceramic engine" has faded and is replaced with a more realistic assessment of ceramics on a part-by-part basis.

Strong concerns remain with reliability/durability aspects of ceramics. In today's quality conscious environment, mistakes are not acceptable.

TECH–41b. Do you foresee any non-engine automotive application for ceramics? Please indicate application and forecast for year and percent application.

The following table shows the non-engine ceramics applications suggested by the panelists. An application that is listed more than once reflects a differing forecast. Twenty percent of the panelists responding to this question indicated that they did not foresee any non-engine applications for ceramics.

Forecast Year	Ceramic Non-Engine Auto Application	Percent Application
1990	A/C compressor shoe	10
	Ceramic electronic chip packages	10
	Ceramic-coated exhaust components	5
1991	Diesel particulate trap	10
1992	Brake components	10
	Ceramic electronic chip packages	10
	Transmission components	10
	Catalytic converters	10
	Smart motors and actuators	5
1993	Sensors	35
1994	Housing for electronics	15
1995	Diesel particulate trap	50
	Transmission components	15
	Electric motor parts	5
	Wheels	5
	New O_2 sensors	5
	Hydraulic pump parts	5
1997	Brake components	40
1998	Brake friction materials	10
2000	Ceramic-coated exhaust components	5

SELECTED EDITED COMMENTS

- Ceramics for electronics substrates are used today in ignition modules, alternator regulators, etc. As more electronics move underhood, this will significantly expand.
- Ceramics are used for elevated temperature resistance where strength is required. Attempts to use ceramics for wear have and always will fail due to ability to redesign and unload (plus lubricate) the wear surface. In addition, producing bearing surfaces in ceramics is very expensive.
- No ceramic applications that are important or seen.
- No ceramic applications before 2000.
- Other areas might be in components for electrical applications and solid-state devices.

- Question has no reasonable boundaries. There are many types of ceramics—many of which have commercial applications today.
- Due to relatively high costs, ceramics applications will be quite limited.

STRATEGIC CONSIDERATIONS

A wide array of non-engine applications are suggested for ceramic materials. While some of the suggested applications are already in place, such as the substrate of a catalytic reactor and various electronic applications, other suggestions encompass a wide range of divergent usage. Although the wide array of suggested applications does not seem to indicate any specific pattern, manufacturing developments and the functional utilization of ceramic materials in automotive components warrant close scrutiny in the years ahead.

This type of question is designed more to generate a qualitative not quantitative vision of the future and capture the general view of people involved in this area of automotive technology.

TECH–42. What percent of the following spark-ignited engine components do you foresee will be made from metal matrix composites (MMC) by the years 1995 and 2000? Do you foresee any other automotive applications for MMC?

MMC Application in Spark-Ignited Engines	Median Response		Interquartile Range	
	1995	2000	1995	2000
Pistons	1%	5%	0/2%	1/7%
Connecting rods	1	5	0/2	1/8

OTHER MMC applications suggested by panelists: Cam followers, piston pin, rocker arm, and gears/sprockets.

SELECTED EDITED COMMENTS

- Again, cost will control application (assuming technology is available). Fifty years of cost reduction and efficiency improvement work will be difficult to improve on.
- Cost will not justify widespread use.
- Cost/benefit will determine rate of introduction.
- More reinforcement for ring grooves necessary if high-mileage warranties are offered. Lightweight connecting rods promise real benefits in noise, vibration, and harshness (NVH). Aluminum particulate composites look promising.

MANUFACTURER/SUPPLIER COMPARISON

As illustrated in the following table, the manufacturer and supplier panelists offer some significantly different forecasts for the percent of spark-ignited engine pistons and connecting rods that will be made from metal matrix composites (MMC). The interquartile ranges of the two groups are also sufficiently divergent to warrant attention, because the wide interquartile ranges indicate a considerable degree of uncertainty.

MMC Application	Forecast for 1995				Forecast for 2000			
	Median Response		Interquartile Range		Median Response		Interquartile Range	
	OEM	Supplier	OEM	Supplier	OEM	Supplier	OEM	Supplier
Pistons	1%	0.5%	0/2%	0/5%	4%	5%	0.5/5%	1/10%
Connecting rods	1	2	0/1	0.5/2	3	5	1/5	2/8

STRATEGIC CONSIDERATIONS

In the last Delphi forecast the materials panelists forecast considerable enthusiasm for metal matrix composites, particularly in some engine components. It is evident that there is growing interest in this technology. However, in general, the panelists do not anticipate substantial commercialization through the next decade. About 5% of engines by the year 2000 are expected to use MMC pistons and connecting rods. With the present emphasis on reduced engine component mass and friction and greater use of high specific power engines, this material and process technology merits careful attention. If some of the recent research activity is successful we would not be at all surprised to see usage accelerate beyond the levels forecast.

TECH-43. What applications for electro-rheological (ER) fluids do you foresee by the year 2000?

Application for Electro-Rheological (ER) Fluids by the Year 2000	Percent of Total Responses
Engine Mounts	24%
Drivetrain Applications	20
Shock Absorbers	18
Active-Suspension Components	14
Accessory Drives and Clutches	14
Four-Wheel-Drive Couplings	6
No Applications	4

The following applications received significant responses within each primary category and are shown as percent of responses within that category.

	Percent Responses Within Category
Drivetrain Applications:	
Torque Converter	25%
Limited Slip Differential	17
Continuously Variable Transmission	8
Accessory Drives and Clutches:	
Air Conditioning Clutch	56
Alternator Clutch	11

REPRESENTATIVE RESPONSES

- Shocks are an obvious potential application for ER fluids.
- Air-conditioning clutch—other accessory drives.
- Clutches possibly. Shock absorbers possible but not likely. Engine mounts possible but not likely.
- Torque limiters.
- Light-duty CVTs.
- Engine mounts and torque converters if made to be robust enough for production vehicles.
- Fan clutch. Alternator clutch.
- Fluid coupling in all-wheel-drive (AWD) differential.
- Where variable rates are important for refined function. Use depends on reasonable cost/benefit.
- Low-level probability of use in active-suspension components.
- Lubricants. Energy dampening—suspension.
- Maybe in variable-shock/strut damping.

- None. Designs that would live in the automotive applications being proposed would have to be available within five years. We do not see that happening at this point. Still a research item.
- Perhaps transmission converter lock-ups.
- Replacement of current viscous-coupling technology applications. Possible damper for gear noise in transmissions, both manual and automatic.
- See none at this point. Shift in vehicle configurations may present an opportunity for very small niche market.
- Door/hatch hinges.
- Semi-active engine mounts.

STRATEGIC CONSIDERATIONS

Electro-rheological fluids have sparked considerable interest within the automotive industry during the past several years for a number of key applications. Potential applications are suggested in the responses to this question. Recent developments in these fluids have enhanced their properties and abilities to function in a variety of different environments that are crucial to automotive applications. As with any relatively new technology, the developments must be followed closely. Some of the particularly challenging problems these fluids would have to meet in automotive applications include extremes in temperature and long-term durability. Clearly, the characteristics of the fluids would fit well with the increase in overall electronic control in the vehicle. However, based on the information available to date, by no means can commercialization be assumed at the present time. Still, this is a very intriguing and potentially important development.

III. POWERTRAIN/DRIVETRAIN

TECH-44. What percentage of passenger cars and light-duty trucks (and vans) manufactured in North American in 1995 and 2000 (and using a piston internal-combustion engine) will be equipped with engines with the following number of cylinders?

Number of Cylinders	Median Response		Interquartile Range	
	1995	2000	1995	2000
PASSENGER CARS				
3 Cylinders	0%	1%	0/1%	0/3%
4 Cylinders	50	47	44/53	38/55
6 Cylinders	30	35	29/35	28/40
8 Cylinders	20	17	15/22	10/22
10–12 Cylinders	0	0	0/1	0/2
LIGHT-DUTY TRUCKS				
3 Cylinders	0%	0%	0/0%	0/0%
4 Cylinders	14	15	10/16	10/20
6 Cylinders	50	50	47/50	46/55
8 Cylinders	36	35	35/40	28/40
10–12 Cylinders	0	0	0/0	0/0

SELECTED EDITED COMMENTS

- Cheap fuel and performance interests will drive the market upscale.
- Depends on fuel availability but more cylinders/displacement likely.
- Imported 8-cylinder engines will increase.
- Six is the right number.
- Smaller V-8s will keep the V-8 percentage up through the mid-1990s.
- The flex will occur between 4-cylinder and 8-cylinder; 6-cylinder will remain relatively constant for passenger cars.
- V-10 will be limited volume, single manufacturer.
- Some V10 passenger-car engines (<1%) also anticipated by 2000.
- Light-duty trucks: 10 cylinder is possible at Chrysler—can't believe they'll actually do it.
- Twelve-cylinder engines less than 1% both years.
- Year 2000 mix totally dependent upon energy situation.
- CAFE trends will certainly be a factor.

MANUFACTURER/SUPPLIER COMPARISON

Passenger Cars. The OEM and supplier panelists demonstrated differing perceptions of engine mixes for both 1995 and 2000. As illustrated in the following table, the suppliers forecast a higher median percentage for 4-cylinder engines while the manufacturers forecast there would be a higher percentage of V-8s for each year than did the suppliers.

Number of Cylinders	1995		2000	
	OEM	Supplier	OEM	Supplier
4 Cylinder	45%	52%	40%	53%
6 Cylinder	31	30	35	30
8 Cylinder	20	15	20	14

Light Trucks. The OEM and supplier panelists were in general agreement regarding the median distribution of the number of cylinders in light-truck engines in both 1995 and 2000. The interquartile range for both groups also reveals a reasonably good consensus.

TREND FROM PREVIOUS DELPHI SURVEYS

Passenger Cars. The trend toward increased projections for 8-cylinder engines established in Delphi IV is continued in Delphi V. This is a significant alteration in forecasts for engine mixes first established in the 1979 Delphi I and continued through to Delphi III in 1984. (See table below.)

In the 1979 Delphi forecast, it was projected that 4-cylinder engines would be used in 70% of 1990 U.S.-produced passenger cars. This estimate dropped to 60% in the 1981 Delphi II and continued to drop through Delphi III, leveling out at a Delphi IV forecast of 50%. Delphi IV also forecast 50% of U.S.-produced passenger cars in 1995 would be 4-cylinder. This 50% share for 4-cylinder engines continues through Delphi V. In the Delphi III assessment it was thought that the projected decline in 4-cylinder engines reflected an expected gain for 2- and 3-cylinder configurations. In the 1981 survey it was thought that these engines would account for 12% of the U.S. car market. However, in the 1987 Delphi, the V-6 and V-8 engines were expected to equally divide the U.S. passenger car market with 4-cylinder engines. Delphi V projections support this segmentation through 1995.

Number of Cylinders	Forecast for 1990				Forecast for 1995	
	1979 Delphi I	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
3 Cylinder	N.A.*	10%	2%	0%	2%	0%
4 Cylinder	70	60	53	50	50	50
5 Cylinder	N.A.	5	0	N.A.	N.A.	N.A.
6 Cylinder	25	20	35	30	35	30
8 Cylinder	5	3	10	20	13	20

*Data not available.

Light Trucks. There is a dramatic shift in the forecasts for engine mix in light trucks between Delphi IV and Delphi V. In 1987 it was projected that 4-cylinder engines would be used in 45% of U.S.-produced light trucks. This estimate dropped dramatically to 14% in this Delphi, with the difference being almost evenly distributed between V-6 and V-8 engines.

Number of Cylinders	Forecast for 1995	
	1987 Delphi IV	1989 Delphi V
3 Cylinder	0%	0%
4 Cylinder	45	14
6 Cylinder	35	50
8 Cylinder	20	36

STRATEGIC CONSIDERATIONS

Consistent with other trends in this forecast, we continue to see a moderation of expectations for downsized and lower-powered future vehicles. In fact, compared to Delphi IV, the Delphi V forecast for 1995 V-8 engines is considerably greater than envisioned just two years ago. The Delphi V forecast for 4-cylinder engines in 1995 is the same as Delphi IV. In addition to the market forces prompting this increased expectation for larger engines, we see considerable evidence that manufacturers are expanding their capabilities to improve fuel economy while at the same time maintaining high performance in the larger displacement multi-cylinder configurations. Expectations to the year 2000 strongly suggest that a balance of engine designs will be available to the North American consumer. Optimism for both very small 3-cylinder engines and 10- and 12-cylinder designs is low, even considering some of the projects that are presently underway.

Obviously, a major shift in energy price and availability as well as expectations for future CAFE increases, could again shift interest toward smaller engines. However, with the present panelists' modest expectations for future fuel price increases, they do not believe this is a likely future scenario.

Engines in light trucks are expected to have a greater number of cylinders during the 1990s than was forecast in Delphi IV. In fact, the forecast for light trucks is expected to follow the mix found in 1987 all the way through the year 2000.

TECH-45. On a percentage basis, indicate the mix of spark-ignited engine displacements you expect in North-American-produced passenger cars made in 1995 and 2000.

Displacement in Liters	Median Response		Interquartile Range	
	1995	2000	1995	2000
5.1+	3%	2%	2/4%	1/4%
4.1–5.0	18	16	15/20	10/20
3.1–4.0	19	21	15/20	15/25
2.1–3.0	50	51	45/53	43/54
1.5–2.0	10	10	8/12	8/15
Below 1.5	0	0	0/1	0/2

SELECTED EDITED COMMENTS

- No big changes, but slight size increases.
- No major shift due to refinements to improve fuel economy, performance, noise, vibration, harshness, etc.

MANUFACTURER/SUPPLIER COMPARISON

There is agreement between the manufacturers and suppliers regarding engine displacements in 1995 and 2000. The interquartile ranges also indicate a good consensus.

TREND FROM PREVIOUS DELPHI SURVEYS

The trends toward increasing engine size as measured by displacement appears to be leveling off. As demonstrated in the table below, it was forecast in Delphi IV (1987) that in 1995, 36% of the engines would be in the 3–5 liter displacement range. In this Delphi, the percentage is estimated to be 37% in 1995. Engines in the 1.5–3.0 -liter range projected in Delphi IV to be 57% in 1995 are forecast to be 60% in Delphi V.

Displacement in Liters	Forecast for 1990			Forecast for 1995	
	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
5.0+	0%	5%	6%	2%	3%
3.0–5.0	15	30	38	36	37
1.5–3.0	66	55	53	57	60
Below 1.5	19	10	3	3	0

STRATEGIC CONSIDERATIONS

Expectations for engines in the 3.0–5.0+ range by 1995 are greater in Delphi V than forecasts expressed in Delphi IV. This suggests that in North America we will continue to favor displacement increases as a means to expand power rather than make extensive use of high technology, high-specific-output engines. Of course, all domestic manufacturers are engaged in major engine programs featuring upsizing, downsizing, and up-teching of their engines. In reality all could occur with the wide variety of engines being developed for our complex multi-segmented market. This forecast, obviously, reflects the rather strong customer interest in greater performance. We believe the *Strategic Consideration* section from Delphi IV bears repeating.

> The U.S. manufacturers have greater flexibility with regard to engine displacement, since most foreign manufacturers build engines for use in foreign countries with heavy taxation on larger-displacement engines. Consequently, both European and Japanese engines place a premium on specific output, whereas U.S. manufacturers have the option of utilizing greater displacement to achieve the same overall performance level. A major uncertainty remains with respect to future energy price/availability trends and the consumer's demand for so-called high-tech engines that incorporate features such as fast-burn chambers and multi-valve cylinder heads, all of which tend to increase specific performance. American manufacturers on the average will utilize larger engines but with a reasonable increase in factors that will improve specific output.

A rule of the market is "know thy customer." Does the customer care about how power is achieved, i.e., through either high-tech features or displacement? Some obviously are demanding greater feature content, e.g., four-valve heads; but most are more interested in function without regard to technology content. Market forces will be a key factor. The cost of increasing power via expanded displacement is difficult to beat. CAFE standard increases could accelerate move to higher-specific-power, smaller-displacement engines. However, greater displacement but still *high precision* engines may offer almost equivalent economy at comparable performance to "high-tech" designs. This is a controversial issue that needs further illumination. 1990s.

TECH-46. What percentage of North-American-produced light-duty vehicle engines will utilize the following valve-train configuration in 1995 and 2000?

Valve-Train Configuration	Median Response		Interquartile Range	
	1995	2000	1995	2000
Push Rod	60%	45%	50/65%	26/50%
Single Overhead Cam	30	35	25/30	30/45
Dual Overhead Cam	10	20	10/15	15/30

SELECTED EDITED COMMENTS

- Japanese firms already lead the way.
- Overhead cams and multi-valves will prove to be ineffective from cost and packagability standpoints.
- Push-rod engines will eventually die out.
- Ultimately the most prevalent system will be cost driven.
- Single overhead cam (SOHC) four-valve configuration growing rapidly. Dual overhead cams four-valve for high output/performance engines.
- Difficulty in packaging double overhead cam (DOHC) engines (V-6 or V-8) may restrict usage.
- Like four-valve engines, DOHC are expensive fads.
- Must not count out cost-effective push-rod engines. Some customers don't care for high-tech, expensive alternatives.
- Push rods will be relegated to light trucks and low cost vehicle.
- Single cam in block for "V" engines will keep push rods in for cost reasons.

MANUFACTURER/SUPPLIER COMPARISON

The responses of the OEM and supplier panelists were similar, with the interquartile ranges indicating a close agreement on the forecasts.

TREND FROM PREVIOUS DELPHI SURVEYS

Valve-Train Configuration	Forecast for 1995	
	1987 Delphi IV	1989 Delphi V
Push Rod	30%	60%
Single Overhead Cam	50	30
Dual Overhead Cam	20	10

STRATEGIC CONSIDERATIONS

A trend away from the older style push-rod engines is forecast for the 1990s. However, our current Delphi V panelists still see a significant number of push-rod engines in production by the year 2000. Substantial growth is forecast in both single and dual overhead cam designs. This forecast strongly suggests there will be a major value-added opportunity in the valve-train of North-American-produced light-duty vehicle engines during the 1990s. A real question exists whether there is a perceived value on the part of the customer for the technology of SOHC and DOHC designs. It appears that the customer is interested in the overall performance of the engine but perhaps not how that performance is achieved.

Without a doubt the growing demands for increased fuel economy, as well as tighter emission regulations, will play an important role in cylinder head design in the years ahead. New governmental regulations could be a significant factor in promoting even greater use of the overhead cam configurations, i.e., the higher specific performance of these designs can lead to modest improvement in fuel economy and reduced emissions. There is also a growing interest in variable valve timing, multiple inlet flow paths, and other features that could lead to improved performance, emissions, and efficiency. These technologies would have to be designed to mesh appropriately with the valve-train configuration.

New engine types such as the two-cycle engine which does not use a conventional valve train must be carefully tracked by all valve-train component suppliers because of recent developments suggesting this power plant may well be a factor in the latter part of the 1990s.

The comments to this question suggest there is far from a consensus on overhead cam designs.

TECH–47. What percentage of North-American-produced passenger car engines will incorporate the following number of valves per cylinder?

Engines with:	Median Response		Interquartile Range	
	1995	2000	1995	2000
2 Valves per Cylinder	80%	60%	70/83%	50/70%
3 Valves per Cylinder	5	10	5/10	8/15
4 Valves per Cylinder	15	30	10/20	20/35

SELECTED EDITED COMMENTS

- Cost will keep four-valve from 100%. While numbers don't indicate it, three-valve will be very popular. The shift from two-valve to four-valve will occur through the three-valve segment.
- Market is moving toward four valves as being an "entry level requirement" for many segments.
- Two-stroke developments may eliminate poppet valves.
- By the year 2000, two-valve engines will be relegated to light trucks, economy cars, and "old" engines which have not yet been re-tooled.
- By the year 2000, we will see valve systems that are entirely unconventional (i.e., non-tulip shape, non-cam operated). Four-valve is faddish. Cost is prohibitive. It is not the end-all. Two-valve will remain viable. Shift will be from four-valve to three-valve.
- Five- and six-valve engines will be introduced by the year 2000.
- First-round responses underrate speedy changeover to multi-valve engines. They will become necessary to be competitive in performance/fuel economy and will really accelerate as fuel prices increase.
- Pressure to move toward four-valve engines will continue. DOHC will be used to reduce cost for four-valve.
- Valves/cylinder is becoming an engine discriminator.
- Virtually all remaining two-valves will be domestic.
- Four-valve is hands-down winner in driveability, economy, and performance. Toyota leads the way.

MANUFACTURER/SUPPLIER COMPARISON

The only significant differences between manufacturer and supplier forecasts is in the four-valve per cylinder category, where the supplier panelists forecast 12% for 1995 and 23% for the year 2000.

TREND FROM PREVIOUS DELPHI SURVEYS

In 1987 Delphi IV panelists forecast that in 1995, 10% of North American passenger car engines would incorporate three valves per cylinder and 20% would incorporate four valves per cylinder.

STRATEGIC CONSIDERATIONS

One of the most important factors in design of future engine valve trains is perceived value on the part of the customer. While it is apparent that many customers are expecting a higher level of technology in engines, it is uncertain what they are willing to pay for this technology. We believe, however, most customers are interested in the basic performance of engines and not how that performance is attained in terms of engine-feature content. The North American manufacturers will have had the flexibility of increasing power through greater engine displacement rather than through higher specific output engines using such features as 3-and 4-valve heads. The foreign manufacturers in most cases do not have this flexibility in their domestic market because of significant taxes on high-displacement-engines.

The data suggest there will be a spread of technologies in the valve train in the years ahead, and suppliers' of cylinder-head components will need to watch developments carefully. Of course, if a major development should occur in 2-cycle engines, the role of the valve train as we know it today would be altered drastically.

An additional factor to watch closely is the new round of regulatory activity on exhaust emissions and fuel economy. The emission control/fuel economy advantage of the higher-specific-output multi-valve engines could have a profound impact on the valve train of the middle 1990s.

TECH-48. What percent of engines in North-American-produced light-duty vehicles will employ the following valve train technologies in the years indicated?

Valve Train Technologies	Median Response		Interquartile Range	
	1995	2000	1995	2000
Variable Timing Control	5%	10%	1/5%	5/15%
Variable Lift Control	1	5	0/3	2/10

SELECTED EDITED COMMENTS

- Both of these technologies will be evaluated carefully in the next five years; positive benefit will drive utilization.
- This area could grow rapidly, especially if Honda does it first and does it well.
- Expect very limited application in trucks.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in agreement with each other and the consensus median for the percent of light-duty vehicle engines that will utilize variable lift control for the years 1995 and 2000. They differ, however, on the percent application of variable valve timing. While the suppliers forecast 1% and 5%, the OEM panelists forecast 3% by 1995 and 8% by the year 2000.

TREND FROM PREVIOUS DELPHI SURVEYS

As evidenced in the following table, there is a significant decrease from the Delphi IV forecast for the percent of light-duty engines that will employ variable valve timing by 1995.

Percent Light-Duty Engines Employing Variable Valve Timing		
Forecast for 1990	Forecast for 1995	
1984 Delphi III	1987 Delphi IV	1989 Delphi V
5%	10%	5%

STRATEGIC CONSIDERATIONS

There is growing evidence that variable valve lift and/or timing can offer some significant benefits in terms of performance, emissions, and fuel economy. The mechanical problems, however, remain formidable. The forecast by the Delphi panelists for 1995 and 2000 suggest that significant new developments are anticipated, particularly with respect to variable timing. By the year 2000, 10% of the light-duty vehicles are expected to be so equipped. Many uncertainties remain and developments must be watched closely. However, with growing concerns for both emissions and fuel economy, we anticipate activity in this area will accelerate. Whether that will lead to higher levels than forecast is dependent on developments of the next several years. There is considerable room for invention in this area. Considering recent developments in design, materials, lubricants, etc., it also may be appropriate to revisit rotary valve mechanisms.

TECH-49. What percentage of current North-American-production engines will be fundamentally redesigned by 2000?

Engines	Percent U.S. Engines Redesigned by 2000	
	Median Response	Interquartile Range
4-Cylinder	70%	60/80%
V-6	65	50/80
V-8	60	50/80

SELECTED EDITED COMMENTS

- Anticipate introduction of L-5, Flat-6, L-6, V-10, V-12.
- Domestic V-8s are too old to compete with import V-8s. They should be redesigned.
- Fuel economy needs will drive redesign requirements. Much work will be necessary.
- Redesign will be influenced by higher performance expectations, available fuel/emissions technology, and Asian competitors' strategies.
- Japanese competition will force this! Only a few overhead valve V-8s will survive without a major redesign.
- Larger V-8s will require fundamental redesign by that time.
- Modular V-8, V-6, V-4 concept popular by 2000.
- New designs with alternate materials will incorporate most of the changes.
- New V-8s will get the spotlight.
- Required for improved performance and fuel economy and also for more automated and reliable manufacturing.
- This assumes that all existing V-8s will have been dropped from production by the year 2000 and any that are then in production will be new design.
- To me, the engines have never had a fundamental redesign—just evolutionary efficiency improvements, primarily in mixture delivery and accessory systems. I think this trend will continue.
- Virtually all will be redesigned for new valve train configuration, electronic fuel injection, material changes, and other technology advances.
- What does "fundamentally" mean? I am assuming going from two- to four-valves is "fundamental," among other changes.

MANUFACTURER/SUPPLIER COMPARISON

The vehicle manufacturer and supplier panelists are in agreement on the percent of four-cylinder engines they expected to see redesigned by the year 2000. There was, however, some disagreement on V-6 and V-8 engines. Whereas the supplier panelists forecast that 60% of the V-6 and 50% of the V-8 engines would be redesigned by the year 2000, the OEM panelists forecast 70% for both.

TREND FROM PREVIOUS DELPHI SURVEYS

Delphi IV projected that the percentage of North-American-production engines that would be fundamentally redesigned by 1995 would be as follows: 4–cylinder 60%; V–6 50%; and V–8 40%.

STRATEGIC CONSIDERATIONS

Panelists in Delphi V expect a greater level of total engine redesign by 1995 than was forecast in Delphi IV. The level of redesign forecast is rather extensive. Considering that engine plants are extremely expensive, this suggests massive investment by the North American industry. Since the customer places high value on engine function, many of the relatively old designs still present in North-American-produced vehicles will have to be redesigned to bring them to world-class levels. We anticipate a fierce competitive battle for investment between engines and other vehicle systems that are also candidates for redesign in the years ahead. There is no question that this massive level of redesign will have significant implications on the machine-tool community, as well as engine component suppliers. The forecasts suggest this segment of the industry not only faces an important opportunity, but also a significant threat to existing business. One thing is very clear regarding these new engines: they will be far more precise mechanisms than those that preceded them, and in general, their components will be characterized by a much higher level of micro-precision. Suppliers will have to meet the more rigorous specifications for future engine components to remain competitive.

TECH-50. What percentage of North-American-produced passenger cars will utilize two-cycle gasoline engines in the years 1995, 2000, and 2005?

North-American-Produced Passenger Cars Using	Median Response			Interquartile Range		
	1995	2000	2005	1995	2000	2005
Two-Cycle Engines	0%	2%	5%	0/1%	0.1/5%	0.1/10%

SELECTED EDITED COMMENTS

- Assumes that current efforts on electronic direct injection are successful.
- Could go to 50% plus by year 2000. Not a customer issue as much as an engineering issue.
- Depends on the outcome of current development programs related to hydrocarbon emissions.
- Emissions control complexity and the potential of tougher emissions control will delay, if not stop, the two-cycle engine.
- Higher "power density" may be realized by other technologies rather than two-cycle engine.
- If the technology on hydrocarbons and noise, vibration, and harshness (NVH) is developed, I see a major usage of two-cycle engines because of their high specific output per package size.
- Inefficient combustion and rotary alternatives will cause this concept to stall.
- Many incentives, but also many hurdles to overcome (noise, emissions).
- Present need for mixing fuel will deter application in passenger vehicles.
- No clear advantages yet for two-cycle. It'll be a gimmick first, then if benefits are demonstrated, increases will come.
- Orbital engine holds a great deal of promise. Unlike past "wonder motors" (i.e., rotary), it does not require major tooling changes, expense, or emissions/fuel economy problems.
- I think the Orbital two-cycle approach will be commercialized, particularly in small economy cars.
- Use of two-cycles will be dependent on future EPA hydrocarbon exhaust emission standards. Tighter standards, cold weather standards, or longer durability may keep the two-cycle out of the U.S. passenger car market.
- Use will depend as much on problem of obsolescence of current four-stroke manufacturing equipment as on the technology barriers to meet emissions.
- Once existing technical hurdles are overcome, two-cycle engines will still have a very limited market due to displacement limitations.
- Probably won't make it—but just might.
- The technology is likely to be piloted outside of U.S.
- Too early to call.
- Tough question! Depends on more than just technology availability.

MANUFACTURER/SUPPLIER COMPARISON

Both the OEM and supplier panelists were in agreement with the median forecasts presented for all three years. The supplier upper quartile of 10% for the year 2000, however, was much higher than the manufacturers' panelists upper quartile of 6%.

TREND FROM PREVIOUS DELPHI SURVEYS

Panelists for the Delphi IV forecast that 3% of U.S.-produced passenger cars would utilize two-cycle gasoline engines by 1995.

STRATEGIC CONSIDERATIONS

As was predicted in our prior Delphi IV forecast, there is an undercurrent of interest in the two-cycle gasoline engine, but a significant number of questions remain. A wide variation in expectations is evident, which is a measure of the uncertainty about this future technology. Because of the dramatic impact this engine could have on the entire automotive industry, very little public comment is being made other than by those few who are trying to market two-cycle-engine technology. Although there are several other issues, the concern with hydrocarbon emissions remains as perhaps the most significant.

Incentives for the two-cycle engine remain very strong. These include a smaller package size, potentially lower cost, and almost twice the power density of four-stroke designs and possibly improved fuel economy. The first manufacturer able to bring an effective two-stroke design to market would have a strategic competitive advantage. This engine has the potential to make current engine technology obsolete, but at this point it cannot be assumed nor can any high level of probability be ascribed to the future of the two-cycle. However, because of the magnitude of effect it could have on the entire industry, this technology must be followed closely by all in the engine area. Even a modest conversion to a two-cycle design could have a profound impact on suppliers of numerous engine components, e.g., valves and camshafts. Additionally, there would be considerable impact on a number of other factors related to the overall vehicle package. It will be extremely interesting to watch two-cycle progress in the next few years.

TECH–51. What percentage of vehicles manufactured in North America in the listed years will be equipped with diesel engines?

U.S.-Produced with Diesel Engines	Median Response		Interquartile Range	
	1995	2000	1995	2000
Passenger Cars	0%	0%	0/0.3%	0/1%
Light Trucks/Vans	3	3.5	2/4	2/5

SELECTED EDITED COMMENTS

- Anticipate some new technology to make diesels smoother, quieter. Will start with commercial applications, where fuel cost is of concern.
- Assume clean burn and performance technology will drive small increases.
- Barring a major disruption in fuel supply and diesel technology breakthroughs, e.g., high efficiency adiabatic plus quiet and easy to start in cold weather. 0% diesel engines in passenger cars through year 2000.
- Diesel emission regulations will make gasoline-powered vehicles a better deal.
- Diesel will be hard to justify unless they are subsidized.
- Diesels will come back, but slowly.
- Fuel economy needs will rekindle diesel's spark.
- The answer on this question could be affected by the definition of the "diesel engine." Alternative fuel, such as methanol, would be used in compression-ignition engine (sometimes spark-assisted). Is this a "diesel engine?" How about gaseous-fueled engine, dual-fueled engine?
- The diesel would have to be forced in by fuel price situation or other external factors. The diesel has a bad reputation (perhaps undeserved) as unreliable and as a no-acceleration polluter. Tough to overcome that combination.
- Rate of increased penetration will be dependent on emissions regulations and/or world fuel supply situation.

MANUFACTURER/SUPPLIER COMPARISON

Both the manufacturer and the supplier panelists were in general agreement with the forecast combined median.

TREND FROM PREVIOUS DELPHI SURVEYS

As demonstrated in the table below, the precipitous decline of the diesel engine as a powerplant in U.S.-produced passenger vehicles appears to be complete.

U.S.-Produced with Diesel Engines	Forecast for 1990				Forecast for 1995	
	1979 Delphi I	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
Passenger Cars	25%	20%	10%	2%	3%	0%
Light Trucks/Vans	N.A.*	25	20	10	15	3

*Data not available.

STRATEGIC CONSIDERATIONS

Following the trend that was clearly evident in Delphi IV, enthusiasm for the future of the diesel, particularly in North-American-produced passenger cars, is very low. The panelists are slightly more enthusiastic about the future of diesel engines in light-duty trucks and vans. However, even in this category expectations are relatively low, significantly lower than has been forecast in all prior Delphi studies. This forecast would likely be altered to some extent should a new energy crisis emerge. Also, since the fuel economy performance of the present fleet has improved so dramatically compared to the 1970s, the incentives for use of the diesel are substantially less than they were a decade ago. Additional factors limiting the prospects of the diesel include high cost, low power, problems with noise, smoke, and emissions can be difficult to control, particularly nitrogen oxide and soot. Research obviously is continuing and significant progress is being made, particularly in Europe. Nevertheless, prospects for the future of diesel engines in North America appears to be as dim as the panel has suggested.

TECH–52. What percent of North-American-produced passenger cars and light-duty vehicles will incorporate the following advanced engine types in the years 1995 and 2000?

Engine Types	Median Response		Interquartile Range	
	1995	2000	1995	2000
Open-Chamber (DI) Diesel	0.1%	1%	0/2%	0/3%
Stratified Charge Spark-Ignited	1	3	0/5	0/10
Low-Heat Rejection Engine	0	2	0/3	0/7
Rotary Combustion or Wankel	0	0	0/1	0/1
Gas Turbine	0	0	0/0	0/1

SELECTED EDITED COMMENTS

- Barring a major petroleum crisis, the incentives for advanced engine types are not strong enough!
- Industry is not interested in new engine technology.
- Diesels will progress with D.I. for commercial applications. Ceramics hold promise for low-heat rejection engines.
- The open-chamber (D.I.) diesel will be 100% of diesels by 1995.
- Gas turbine cost is problem. Wankel won't solve its fuel economy and emissions problems.
- Particulate emissions would be a restriction in open-chamber (D.I.) diesel. Improved fuel preparation could be more effective in stratified-charge spark-ignited engine. Low-heat rejection engine possible in heavy-duty diesel engine only. Rotary combustion or Wankel—no way in American-produced cars. Even if ceramic gas turbine could improve fuel economy, cost would be a restriction.
- It is tough to beat the cost-per-horsepower and mpg of spark-ignited internal combustion engine.
- If methanol becomes more widely used or legislated, then stratified-charge engine use may increase.
- Five percent by 2000 forecast for gas turbine is dependent on a move to alternate fuels and overseas market pressures.

MANUFACTURER/SUPPLIER COMPARISON

A comparison of OEM and supplier panelists reveals a considerable difference of opinion regarding expectations in 1995 for the incorporation of the advanced engine types surveyed. Whereas the OEM panelists forecast 0% for all advanced engines, the supplier panelists felt that open-chamber diesels would be 1% in 1995, stratified-charge engines 5% with an upper quartile range of 15%, low-heat rejection engines 1% with an upper quartile range of 5%, and Wankels would be 0.5% with an upper quartile range of 2%. The suppliers agree with the manufacturers that gas turbines would be 0%.

TREND FROM PREVIOUS DELPHI SURVEYS

A comparison of current forecasts with Delphi IV indicates a decrease in expectations for every advanced engine type surveyed.

Engine Type	Forecast for 1995	
	1987 Delphi IV	1989 Delphi V
Open-Chamber (DI) Diesel	5%	0.1%
Stratified-Charge Spark-Ignited	5	1.0
Low-Heat Rejection Engine	2	0.0
Rotary Combustion or Wankel	1	0.0
Gas Turbine	0	0.0

STRATEGIC CONSIDERATIONS

The future prospects for a number of alternative engine types were reviewed in this question. As is evident from the panelists' responses, there is limited expectations that any design will be commercialized in any significant quantities before the year 2000. Obviously, developments must be watched closely in all of these engine configurations, particularly in light of some of the growing concerns for fuel economy and emissions. In general, enthusiasm for all of these power plants was less than was demonstrated in our prior Delphi IV forecast. This suggests that progress with existing power plants has been substantial and they will remain a formidable competitor for many years.

It is imperative to have worldwide vision in reviewing alternative power plants. Progress in such engines as the direct injection (DI) diesel seems to be significant in some areas of the world, particularly in Europe. Other power plants such as the low-heat rejection diesel may be more applicable to heavy truck or commercial types of applications rather than light-duty vehicles, at least for the next decade.

TECH–53. What percentage of North-American-produced passenger car engines will incorporate the following technical features by the year 1995 and 2000?

Technical Features	Median Response		Interquartile Range	
	1995	2000	1995	2000
Fast-Burn Combustion Chamber	65%	80%	60/80%	80/90%
Roller Lifters	40	60	35/50	50/70
Balance Shaft: 4-Cylinder Engines	20	40	20/30	30/50
Balance Shaft: 6-Cylinder Engines	20	20	10/25	15/30
Variable Valve Timing	5	10	2/5	7/20
Lean-Burn Technology (General)	5	15	3/10	5/30
Powdered Metal Cam and Gears	10	20	5/10	10/25
Hollow Camshaft	10	20	5/10	10/25
Twin Spark Plugs per Cylinder	2	4	1/5	2/8
Axial-Stratified Charge (ASC)	1	2	0/1	1/2
Plasma (or other advanced) Ignition	1	2	0/1	1/5

SELECTED EDITED COMMENTS

- "Free" improvements as engines/components are redesigned will proliferate, i.e., fast-burn combustion chambers.
- Big advancements will be made in ignition systems. All aimed at more precise firing.
- Lean-burn technology is not practical at current and future emission levels. Roller lifters will be used only on push-rod engines, and will be phased out with them.
- Roller lifters will decrease as number of push-rod engines decrease. Balance shafts will decrease as small V-6s replace in-line 4s and new V-6s are designed to be 60°. Lean-burn is dependent on development of direct injection.
- Applications rate will be cost/benefit driven.
- Axial-stratified charge is at best a fuzzy concept—most engines will be sequential fuel injection (SEFI), but not specifically "ASC."
- Four-cylinder engines over 2.0-L require balance shaft or lightweight rotating and reciprocating components. Ninety-degree V-6 engine also requires balance shafts unless offset by components.

MANUFACTURER/SUPPLIER COMPARISON

The following table represents the differences between the OEM and supplier panelists' forecasts for the listed technical features in 1995.

Technical Features	Forecast for 1995	
	OEM	Supplier
Fast-Burn Combustion Chamber	75%	60%
Roller Lifters	45	40
Balance Shaft: 4-Cylinder Engines	20	25
Balance Shaft: 6-Cylinder Engines	15	20
Twin Spark Plugs per Cylinder	2	3
Axial-Stratified Charge	0	1

TREND FROM PREVIOUS DELPHI SURVEYS

As illustrated in the table below, with the exception of a balance shaft in 6-cylinder engines, there has been a reduction in the percentages forecast for the listed technical features in North-American-produced passenger cars in 1995.

Technical Features	Forecast for 1995	
	1987 Delphi IV	1989 Delphi V
Fast-Burn Combustion Chamber	75%	65%
Roller Lifters	50	40
Balance Shaft: 4-Cylinder Engines	25	20
Balance Shaft: 6-Cylinder Engines	10	20
Variable Valve Timing	10	5
Lean-Burn Technology (General)	20	5
Powdered Metal Cam and Gears	20	10
Hollow Camshaft	15	10
Twin Spark Plugs per Cylinder	5	2
Axial-Stratified Charge	2	1
Plasma (or other advanced) Ignition	2	1

STRATEGIC CONSIDERATIONS

A significant shift has occurred from Delphi IV to Delphi V in expectations for a number of advanced engine technologies during the next decade. Still rapid growth is expected in most of the technologies although less than forecast in Delphi IV. For example, for 1995 the expectations for roller lifters have been reduced to 40% from 50% in Delphi IV.

As noted in several other questions, the "up-teching" of engines to a certain extent will depend on perceived customer value as well as stricter emissions and fuel economy standards. We believe that future regulatory issues will have a profound effect on engine technology, and where reasonable fuel economy and/or emission improvements are found, the application rate of these technologies could accelerate significantly. The prospects for tougher CAFE standards are particularly important.

Some of the technologies such as twin spark plugs per cylinder, axial stratified charge engines, and plasma ignition apparently remain more curiosities. Of all the technologies explored in this question, the only one with increased expectations over Delphi IV was the use of balance shafts in six-cylinder engines. The comments should be read carefully because of other suggestions for future engine changes. With the high level of redesign expected in future engines, competitive and regulatory uncertainties abound.

TECH-54. What percent of North-American-produced spark-ignited engines for light-duty vehicles will be either supercharged or turbocharged in models years 1995 and 2000?

Gasoline Engines	Median Response		Interquartile Range	
	1995	2000	1995	2000
Supercharged	2%	3%	1/5%	1/5%
Turbocharged	5	5	4/5	4/10

SELECTED EDITED COMMENTS

- Both methods are expensive to install and maintain. Not good for most users.
- Dual overhead cams may replace turbochargers and superchargers. This is now occurring in Japan.
- Four-valve engines and fast-burn technology will keep the need for turbocharging and supercharging from becoming significant.
- If there is an energy crisis, turbocharging would increase significantly.
- None (I hope). Turbocharging should be reserved for diesels.
- These will be primarily for the performance market.
- Superchargers are much better suited to U.S. driving habits and desires than are turbos.
- These are crutches. Displacement or more cylinders are preferable technique to meet customer wants: performance together with durability and reliability. Engine compartment heat management favors supercharging over turbocharger.
- Total compression induction will remain constant. Supercharging will make slight inroad at expense of turbos.
- Variable geometry turbos will be used. Superchargers remain bulky and must be clutched-out when not accelerating.
- Given power/weight ratio legislation by year 2000, supercharging will be 20% and turbocharging will be 15%.

MANUFACTURER/SUPPLIER COMPARISON

The OEM and supplier panelists were in agreement on the median percentages forecast for turbocharging in both 1995 and 2000. The two panelist groups differed, however, on projections for supercharging, with the manufacturer panelists forecasting 1% in 1995 and 2% in the year 2000. The supplier panelists, on the other hand, gave more optimistic forecasts of 2% in 1995 and 4% in 2000.

TREND FROM PREVIOUS DELPHI SURVEYS

Previous forecasts for the percentage of North-American-produced passenger vehicles that would be turbocharged in 1990 experienced a dramatic reduction from a high of 25% in the 1979 Delphi to 10% in 1981. This 10% estimate held steady through Delphi II and Delphi IV. The Delphi IV forecast for 1995 was also 10%. The current forecast of 5% is one-half of these previous forecasts. The very close interquartile ranges indicate a strong consensus on this percentage.

Previous forecasts for supercharging also indicate a downward trend. From a Delphi II high of 5% in 1990, projections for supercharging in 1990 slipped to 2% in Delphi III and 1% in Delphi IV. Delphi IV panelists expected a rise to 4% in 1995 but current Delphi V estimates have again declined to 2% in 1995.

STRATEGIC CONSIDERATIONS

The enthusiasm of our Delphi panelists for both supercharging and turbocharging has remained modest over the years. This trend continues with the present forecast, which envisions a modest role for both technologies; but neither is expected to exceed 5% of production. The decreased enthusiasm for the supercharger is somewhat surprising, particularly in light of the fact that the first production supercharged North American engine has been released this year. The panelists, however, apparently feel that these are rather sharply focused on specialty- or elite-image vehicles within models and may not have broad appeal in the marketplace, considering the significant cost. Of course, should designs emerge that are significantly lower in cost with attractive packaging and no serious deficiencies, external boost could surge significantly. Another key question with respect to external boost relates to the trade-off between boost devices and greater engine displacement. Increasing engine displacement is generally less costly.

TECH-55. What percent of North-American-produced light-duty vehicles will have *active* engine mounts in the following years?

Percent Light-Duty Vehicles with Active Engine Mounts			
Median Response		Interquartile Range	
1995	2000	1995	2000
2%	6%	1/5%	2/15%

SELECTED EDITED COMMENTS

- A luxury vehicle feature aimed at noise, vibration, harshness (NVH) problems.
- Another gimmick.
- Offers some opportunity to improve 4-cylinder NVH. Ford, GM, and Chrysler can't continue current levels of 4-cylinder NVH into the 1990s.

MANUFACTURER/SUPPLIER COMPARISON

The panelists are in accord on the percent of light-duty engines that will have active engine mounts in 1995. For the year 2000, the OEM panelists forecast 5% active engine mounts; the supplier panelists forecast 7%.

STRATEGIC CONSIDERATIONS

Recent technological advances have given rise to the possibility of using active engine mounts that can potentially be incorporated in the overall electronic control strategy of the vehicle to provide a high level of powertrain isolation from the vehicle. Technology such as electro-rheological (ER) fluids in engine mounts and other technologies appear to hold promise. Modest application of active engine mounts is anticipated during the latter part of the 1990s. A continuing emphasis on smaller, lighter, high-specific-output engines could accelerate the trend toward active mounts because of problems with engine vibration in many engine configurations. Also, the customer is clearly demanding increased levels of overall vehicle pleasability. This suggests that better powertrain isolation would be well received.

TECH-56. What percentage of North-American-produced passenger cars with spark-ignited engines will incorporate the following ignition systems in the years indicated?

Ignition Systems	Median Response		Interquartile Range	
	1995	2000	1995	2000
Knock Control	30%	60%	30/35%	50/80%
Distributorless Ignition Systems	40	75	35/50	65/80
Individual Cylinder Control of Ignition	40	75	35/50	65/80
Closed-Loop Timing	10	25	5/30	20/45
Coil-On-Plug Ignition	5	15	5/10	10/20

SELECTED EDITED COMMENTS

- Cost will be the determining factor except for ignition timing systems. They will be 100% by 2000 because of the tremendous accuracy advantages.
- Direct optical combustion measurement could be an upcoming technology that affects how precombustion is sensed and handled.
- Individual control of cylinder for knock control is the only sensible interpretation of this system. There does not seem to be a rationale for unique spark calibrations per cylinder by design.
- Knock control is only feasible technology. Individual cylinder control has limited application due to high cost. Coil-on-plug: high temperature durability issues.
- Several Japanese production engines already have these features, and will force the technology
- Success with variation reduction of cylinder-to-cylinder and engine-to-engine compression ratio could negate much of the current interest in listed items.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in general agreement with each other for 1995. Except for distributorless ignition systems, where supplier panelists forecast 80% versus 75% for OEMs, they are in agreement with regard to the percent of ignition systems for the year 2000. The interquartile ranges also indicate good consensus.

TREND FROM PREVIOUS DELPHI SURVEYS

As indicated in the following table, Delphi V panelists have tempered the enthusiasm for incorporation of the indicated ignition systems forecast by Delphi IV panelists.

Ignition Systems	Forecast for 1995	
	1987 Delphi IV	1989 Delphi V
Knock Control	55%	30%
Distributorless Ignition Systems	50	40
Individual Cylinder Control of Ignition	20	10
Closed-Loop Timing	15*	10
Coil-On Plug Ignition	*	5

*In Delphi IV coil-on-plug and closed-loop timing were considered a single category.

STRATEGIC CONSIDERATIONS

Significant changes are anticipated in ignition systems in the years ahead, although the rate of change is somewhat less than anticipated in previous Delphi forecasts. However, the rate of change is still substantial. It is evident, based on the large spread of the interquartile range, that there is still significant uncertainty as to the role these various technologies will play. Suppliers of ignition components need to be cognizant of the new technologies and well aware of how they will alter the basic ignition system in the years ahead. Certainly with the probable new emission control requirements and possible further tightening of fuel economy standards, emphasis on these technologies could be even greater than forecast. In any event, there is a major thrust to optimize the combustion process within each individual cylinder in order to optimize overall system performance.

Of course, new emerging technologies could have an important impact. For example, Toyota is developing what seems to be a direct cylinder injection gasoline/diesel hybrid-type of an engine. Technology such as this could have a profound effect on ignition system components.

TECH-57. What percent of North-American-produced *passenger cars* with spark-ignited engines will be produced with the following types of fuel-management systems in the years 1995 and 2000?

Fuel Management System	Median Response		Interquartile Range	
	1995	2000	1995	2000
Fuel Injection				
Throttle Body (single point)	35%	25%	30/35%	15/30%
Port or multi-point	60	75	60/70	70/85
Carburetion	5	0	2/5	0/1

SELECTED EDITED COMMENTS

- Central port injection (injector-plus distribution tubes) will replace most port or multi-point by 2000/2005.
- Cost reduction and performance improvements will lead to virtually all multi-point systems.
- Demise of carburetors is imminent. Throttle-body injection (TBI), because of cost, will remain nearly constant.
- Emphasis will be on making port systems more cost effective. Emission requirements will squeeze out carburetors.
- Multi-point injectors (MPI) may go even higher, depending on fuel cost and equipment cost.
- Advantages of port-type vastly outweigh costs.
- CPI will replace 50% of multi-port by year 2000.
- Low-cost fuel injector will be an enabler for multi-point injection (MPI). Single point with distribution tubes will replace much of TBI volume.
- Low-cost injector technology will drive the performance/cost improvements so that multi-point is predominant by the year 2000.
- One or two injectors are less costly than four or six and TBIs give most of the benefits of MPIs.
- Single-point with distribution tubes is going to be another GM cost-reduced half-step! They will see the light by the year 2000.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in agreement regarding the percent of North American passenger vehicles that would utilize the fuel management system surveyed.

TREND FROM PREVIOUS DELPHI SURVEYS

In both the 1984 Delphi III and the 1987 Delphi IV, panelists forecast that in 1990, 50% of North-American-produced passenger cars would utilize throttle-body fuel management systems. As indicated in the table above, both Delphi IV and Delphi V panelists expect this percentage to decline to the 35–40% range by 1995. As indicated in the data presented and the panelists' comments, multi-port injection (MPI) appears destined to become the predominant fuel management system into the next century. Although the forecasts indicate that the traditional spark-ignited engine carburetor will demonstrate a presence through 1995, the decline indicated by trend data should be completed by the year 2000.

Fuel Management Systems	1984 Delphi III		1987 Delphi IV		1989 Delphi V	
	1990	1992	1990	1995	1995	2000
Throttle Body	50%	50%	50%	40%	35%	25%
Port (multi-point)	25	30	40	58	60	75
Carburetion	25	20	10	2	5	0

STRATEGIC CONSIDERATIONS

Although the Delphi V forecast for 1995 use of carburetors was slightly greater than in Delphi IV, it is clear that the traditional spark-ignition engine carburetor will continue to fade from the scene. It may continue to appear only in entry-level vehicles. Undoubtedly, there will be market opportunities in the aftermarket, but this does not appear to be the case at the OEM level. Expectations for multi-point fuel injection continue to grow. It is anticipated that three-quarters of the cars produced in the year 2000 will use this fuel management system, with the remainder using the single-point design. Obviously, any participant or supplier of fuel-management systems must be well underway towards a conversion to electronic injection technology to ensure a long-range business position. It will be particularly interesting to watch some of the variations that appear in multi-point injection technology, particularly with some of the micro-injectors and other emerging technical features. Furthermore, it is clear that we will see more highly tailored sequential types of injection systems as this technology improves.

TECH-58. What percentage of North-American-produced *passenger cars* will use the following drivetrain configurations in the listed years?

Drivetrain Configuration	Median Response		Interquartile Range	
	1995	2000	1995	2000
Front Engine, Front Drive	79.0%	80.0%	75/80%	74.5/85%
Front Engine, Rear Drive	17.5	14.5	15/20	10/18
Front Engine, 4-Wheel-Drive	3.0	5	2/5	3/10
Mid-Engine, Rear Drive	0.5	0.5	0/1	0/1

SELECTED EDITED COMMENTS

- Front engine, rear drive will not disappear! Customers want large cars.
- Little increase in 4WD demand is expected.
- Mid-engine, rear-drive will be used by specialty cars only.
- Mix will stay pretty close to 1987 levels.
- With anti-wheel spin, rear drive becomes more viable.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in close agreement with regard to the median forecasts for the drivetrain configurations surveyed. Additionally, the interquartile ranges of both groups are almost identical.

TREND FROM PREVIOUS DELPHI SURVEYS

In retrospect, it appears that the 1981 Delphi II forecast that 85% of U.S.-produced passenger cars would be front-engine, front-drive by 1990 may have been overly optimistic. On the other hand, the 1987 Delphi IV forecast of 71% front-drive cars by 1990 may have been a little conservative. The estimate for the 1987 model year stands at approximately 77%, which, coincidentally, is the 1984 Delphi III forecast for 1990. Projections in this current Delphi V of 79% appears to be in accord with the gradual trend toward a dominance of front-engine, front-drive cars in the North American market. When one takes into consideration the upper quartile range, 75% of the panelists felt that this drivetrain configuration would occupy approximately 80% of the market by 1995. This projection holds through the year 2000. While there has been some erosion of the front-engine, rear-drive market, it would appear that this drivetrain configuration is holding its own.

Earlier forecasts that mid-engine, rear-drive cars would account for between 2% and 3% (Delphi III/Delphi IV) of U.S.-produced passenger cars in 1990 and 4% in 1992 also appears to have been overly optimistic. With the demise of the Fiero, however, current projections for rear-engine cars account for only 0.5%, with an interquartile range of 0/1%.

Forecasts for front-engine, four-wheel-drive passenger cars continue to reflect the uncertainty of the industry regarding this configuration. In Delphi IV the panelists forecast a 5% market share for four-wheel drive passenger cars by 1995. The interquartile range was 2/10%, certainly not indicative of a consensus. The current Delphi forecast of 3% for 1995 has an interquartile range of 2/5% and the forecast of 5% for the year 2000 also has a broad interquartile range of 3/10%. It appears Delphi V continues this trend of uncertainty regarding four-wheel-drive passenger vehicles.

Drivetrain Configuration	Forecast for 1990				Forecast for 1995	
	1979 Delphi I	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
Front Engine:						
Rear Drive	25%	15%	20%	25%	17%	18%
Front Drive	75	85	77	71	76	79
Mid-Engine:						
Rear Drive	N.A.*	N.A.	3	2	2	0.5
Front Engine:						
4-Wheel Drive	N.A.	N.A.	N.A.	2	5	3

*Data not available.

STRATEGIC CONSIDERATIONS

While it is apparent that front-wheel drive will continue as the dominant drivetrain configuration through the year 2000, a significant fraction of North-American-produced passenger cars will retain rear-wheel drive. It also appears that there is reduced expectations for both four-wheel drive and mid-engine/rear-drive throughout the next decade. These reductions seem to be in response to the voice of the customer in the present marketplace environment. Considering the customers' expectations for passenger cars, it appears that a prominent role remains for larger, rear-drive as well as high power-to-weight-ratio vehicles. This demand for rear-drive cars could be mitigated somewhat by the expected tightening of both emissions and fuel economy standards.

The front-drive vehicle remains as one of the best ways to provide optimum space efficiency and consequently fuel economy. It will be interesting to watch the strategies of the individual manufacturers unfold with respect to drivetrain configuration. This is a critical decision because of the difficulty and expense in reconfiguring a vehicle, should the market not accept it. The rather significant spread in interquartile values in year 2000 for both front-engine rear-drive and four-wheel drive suggests there is considerable uncertainty among the panelists with regard to these configurations.

TECH–59. Forecast the mix of transmissions for *passenger cars* manufactured in the U.S. in 1995 and 2000.

Transmission Mix	Percent of Total Transmissions			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
MANUAL				
Four Speed	7.5%	5%	5/10%	1.5/8%
Five Speed	5.0	7	3/8	5/10
Six Speed	0.5	1	0/1	0/2
TOTAL	13.0%	13%	12/15%	11/16%
AUTOMATIC				
Three Speed	39	28	25/42	10/35
Four Speed	47	54	42/55	43/62
Five Speed	0	2	0/2	0/5
CVT	1	3	0/2	1/5
TOTAL	87%	87%	85/88%	84/88%
AUTOMATIC STICK SHIFT	0	0	0/0	0/0

SELECTED EDITED COMMENTS

- Believe the three-speed automatic will be phased out in favor of the four-speed automatic. Timing will be governed by economic conditions, manufacturer's conversion time, cost, etc.
- CVT is really an unknown from the standpoint of durability with large engines and customer acceptance.
- CVT will not increase dramatically due to torque capacity limitation.

MANUFACTURER/SUPPLIER COMPARISON

Although the median percentages forecast by the manufacturers and suppliers demonstrate a good consensus and agreement with the combined results (within 1%), there are some differences. For example, the suppliers project 9% for four-speed manual transmission in 1995, while the OEMs expect a 7% share. For both 1995 and 2000, the suppliers forecast 0% for six-speed manual transmissions, whereas the manufacturers forecast 1% and 2%, respectively. More significant differences are apparent in forecasts for automatic transmissions. These are illustrated in the following table.

Automatic Transmissions	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Three Speed	33%	40%	15%	30%
Four Speed	50	42	57	45
Five Speed	0.5	0	3	0
CVT	1	1	2	4

TREND FROM PREVIOUS DELPHI SURVEYS

A major observation in the trend data is the significant decrease in the forecast for manual transmissions. Total manual transmissions had maintained a consistent 1990 forecast of 32% from Delphi II to 30% from Delphi III through Delphi IV. The 1987 Delphi IV forecast for 1995 was also 30% total manual transmissions. Current forecasts, however, are less than one-half that percentage. Correspondingly, the dramatic increase in the 1995 forecast for three-speed automatic transmissions, from 20% in Delphi IV to 39% in Delphi V, appears to be at the expense of the manuals. The median forecast of 47% four-speed automatic transmissions in 1995 is consistent with the 48% forecast in Delphi IV. The forecasts for continuously variable transmissions (CVT) remain consistently low, with identical median percents of 1% and an interquartile range of 0/1% for both Delphi IV and V.

Transmission Mix	Forecast for 1990			Forecast for 1995	
	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
MANUAL					
Four Speed	18%	15%	10%	5%	7.5%
Five Speed	13	15	20	25	5.0
TOTAL Manual	32%	30%	30%	30%	13.0%
AUTOMATIC					
Three Speed	16%	27%	30%	20%	39%
Four Speed	42	35	40	48	47
CVT	10	8	0	2	1
TOTAL Automatic	68%	70%	70%	70%	87%

STRATEGIC CONSIDERATIONS

A dramatic shift is observed in the forecast for manual shift transmissions in North-American-produced passenger cars. The Delphi V forecast for 1995 is less than half the level forecast in Delphi IV. Obviously, this means significant growth in the use of automatic transmissions. We believe this shift in expectations is based on careful attention to the voice of the customer. The customer today seems to be seeking comfort and convenience, which seems synonymous with automatic transmissions. Furthermore, improvements in fuel economy, reliability, and the high resale value of automatic transmissions have raised their perceived value.

The continuously variable transmission (CVT) continues to have some supporters, although expectations are considerably less than observed in Delphi II and III. With the advent of electronic control in automatic transmissions and more of a systems approach to engine-transmission integration, the automatic transmission is perceived as providing increased value to the customer. Three- and four-speed automatic transmissions appear to be locked in a pitched battle. In the present Delphi there is less difference in expectations for these transmissions than was evident in Delphi IV. Four speeds are more expensive and some newer engines with relatively flat torque curves matched to three-speed automatics can nearly match the overall performance of the same engine with a four-speed. The cost implications of this issue are significant.

TECH-60. What percent of North-American-produced passenger car transmissions will incorporate electronic control (excluding lock-up torque converter) in the following years?

Percent North-American-Produced Passenger Car Transmissions with Electronic Transmission Control			
Median Response		Interquartile Range	
1995	2000	1995	2000
30%	75%	25/50%	60/90%

SELECTED EDITED COMMENTS

- Lock-up torque converters will prevent any real inroads by other transmission controls.
- Electronic transmission control will be incorporated by most four speeds and all CVTs. No manuals or three-speed automatics.
- Electronic transmission control is the biggest advancement in transmissions.
- Chrysler "adaptive controls" will send others back to their drawing boards.
- Electronic transmission controls will be integrated into engine controller and will become more cost effective.
- Electronic shift-speed control will be 50% by 1995. Electronic pressure control 10% by 1995.
- Lock-up torque converters will remain the main type of electronic transmission control.
- Electronic transmission controls required for lower lugging speeds and shift quality improvements.
- Tooling costs and long production lead times are primary factors limiting increased application rates.
- Transmission is one of the engine-related functions that will be increasingly controlled by the "main frame" module.
- Trend has started and will increase rapidly.

MANUFACTURER/SUPPLIER COMPARISON

The median forecasts of the OEM and supplier panelists for both years are in complete agreement with each other.

TREND FROM PREVIOUS DELPHI SURVEYS

In response to a question regarding electronic features, Delphi IV panelists forecast in 1987 that electronic transmission controls would be incorporated in 10% of U.S.-produced passenger cars by 1990 and 25% by 1995. The wide interquartile ranges of those forecasts (5/20% and 15/50%, respectively) indicated a considerable degree of uncertainty on the part of the Delphi IV panelists.

STRATEGIC CONSIDERATIONS

The use of electronic control in automatic transmissions is expected to increase dramatically in the next decade. Generally, the forecast is consistent with Delphi IV and certainly in line with the general increase in the level of electronics throughout the entire vehicle. A major factor prompting electronic transmission control is the increased facility with which the control of the transmission and the engine can be integrated into a total powertrain control strategy. Furthermore, with accelerating competition, the importance of such factors as shift quality and overall performance will prompt a greater application of electronics.

Even as electronic application is increasing, significant improvements have been made in the traditional hydro-mechanical control of modern automatic transmissions, to the extent where they will remain a significant competitor for new electronic transmissions. In addition, tighter emission and fuel-economy regulation may also increase consideration for electronic powertrain management. We suspect that any new automatic transmission offered by the major manufacturers will fundamentally incorporate electronics in the control strategy. Still, we expect that much of the internal actuation will still be accomplished mechanically or hydraulically.

TECH–61. What percent of North-American-produced passenger cars will employ a lock-up torque converter in the following years?

Percent North-American Produced Passenger Cars Employing Lock-Up Torque Converter			
Median Response		Interquartile Range	
1995	2000	1995	2000
80%	90%	60/90%	75/100%

SELECTED EDITED COMMENTS

- All automatics will have lock-up torque converters.
- The technology is known, it's a "good thing" to have.
- Torque converter clutch (TCC) will drop off due to electronic shift control and increased use of five-speed automatic. As those technologies advance, TCC will proportionally decrease. TCC is less a desirable fuel-saving solution than extra gears and electronic control.

MANUFACTURER/SUPPLIER COMPARISON

There is a significant difference between the OEM and supplier panelists in their forecasts on the percent of North-American-produced passenger cars that will employ a lock-up torque converter. The interquartile ranges of both groups are also sufficiently divergent to warrant attention.

Percent North-American-Produced Passenger Cars Employing Lock-Up Torque Converter							
Forecast for 1995				Forecast for 2000			
Median Response		Interquartile Range		Median Response		Interquartile Range	
OEM	Supplier	OEM	Supplier	OEM	Supplier	OEM	Supplier
80%	70%	65/95%	40/80%	95%	80%	80/100%	60/95%

TREND FROM PREVIOUS DELPHI SURVEYS

In 1981, Delphi II panelists forecast that by the year 1990, 90% of both front-drive and rear-drive U.S.-produced passenger cars would be equipped with automatic transmissions that include lock-up torque converters.

STRATEGIC CONSIDERATIONS

The lock-up torque converter is expected to become an almost standard feature in automatic transmissions during the next decade. However, as one expert suggested in the comments, the possible use of five-speed automatics and electronic shift control could decrease the value of the lock-up torque converter. Lock-up converter trends with respect to the overall electronic control strategy in the drivetrain must be watched very closely in the years ahead. Resolution will be based on a true systems analysis of the overall powertrain. Again, as we have noted in a number of other questions, increasingly stringent emission and fuel economy standards may play a prominent role in the decision.

TECH-62. By what year do you foresee the commercial introduction of a continuously variable transmission (CVT) in a *North-American-produced* passenger vehicle?

Forecast Year for Commercial Introduction of CVT Transmission	
Median Response	Interquartile Range
1995	1993/1997

SELECTED EDITED COMMENTS

- At a very low volume.
- Introduction of a CVT will be by a Japanese company. U.S. companies aren't brave enough.
- CVT is really an unknown from the standpoint of durability with large engines and customer acceptance.
- Introduction will be as an experiment on an economy car, perhaps the Ford from Mexico.
- Ford is very close; will probably outsource from Ford Europe for domestically produced vehicles.
- Lackluster introduction in Europe and Japan on small cars (<1.5L) has put a damper on U.S. introduction plans.
- CVTs are limited to cars with engine displacements less than 1.5L.
- It will most likely be a purchased transmission, probably from Ford (Bordeaux, France).
- Must have a successful North American small car.
- Other developments and requirements will keep this low priority.
- Expect pilot program in 1995.
- Unless lightweight vehicle occurs, see little interest in CVT.
- CVTs are not really needed.

MANUFACTURER/SUPPLIER COMPARISON

The supplier panelists forecast that 1994 would be the year in which there will be the commercial introduction of continuously variable transmissions. The OEM panelists forecast 1995 as the year of commercial introduction.

TREND FROM PREVIOUS DELPHI SURVEYS

In 1987 the Delphi IV panelists forecast that 1990 would be the year in which problems associated with the drive belt of CVTs would be resolved and cease to be a major problem inhibiting the application of this transmission type.

STRATEGIC CONSIDERATIONS

As was observed in the earlier question with regard to transmission mix, the prospects of the continuously variable transmission (CVT) are considerably diminished from earlier Delphi forecasts. Still, the median response for the first year of commercial application of the CVT in a North-American-produced passenger car is 1995. General enthusiasm for the CVT, in terms of advantages provided to the vehicle, is also markedly lower than observed in earlier forecasts. Any application will be in a relatively small car. Experience to date in both Europe and Japan indicates that there is not overwhelming consumer support for this transmission. If the original concept of the CVT, which essentially provides the convenience of an automatic transmission with the fuel economy of a manual, should become fully evident to the customer, one could anticipate considerably greater enthusiasm than is presently observed. At this point it appears still to be very much a small-car transmission, which is not generally consistent with the trends of the North American market.

IV. VEHICLE ELECTRONICS/ELECTRICAL SYSTEMS

TECH-63. What fraction of total vehicle dollar value in today's North-American-produced passenger car is represented by electronic componentry, and what will it be in 1995 and 2000? Please include your current estimate.

Fraction Total Vehicle Dollar Value Represented by Electronic Componentry					
Median Response			Interquartile Range		
Current Estimate	1995	2000	Current Estimate	1995	2000
10%	15%	20%	10/11%	12/20%	15/25%

SELECTED EDITED COMMENTS

- Percent content will increase but there will be greater cost reduction in electronic componentry than in other non-electronic components of the car.
- Based upon current cost in dollars per function: I believe electronics costs will continue to decrease and the $1,500 (for the year 2000) will probably be more like $1,000.
- Electric devices will decrease in cost as their usage and standardization increase.
- Functional benefits of electronics for ride control, handling, braking, traction control, and steering are only beginning to emerge.
- In electronic componentry, greater features and performance can often be achieved simply by a software update, so price remains relatively the same or can be reduced by market conditions (i.e., downward price spiral).
- Relative decrease in cost of electronics will largely offset increases in application.
- The electronics will grow but also get cheaper relative to other car parts.
- Two trends counteract each other here; lots more electronic content but because of cost reduction, dollar value will not change dramatically. This cost reduction will accelerate increased electronic content.
- Electronics will peak; too much pure gadgetry.
- Airbag, suspension systems, and ABS will drive electronic systems cost up.
- Cost decrease in electronics will eventually offset increasing number of features, resulting in decrease in cost as percent of total.
- Cost of electronic components will decrease at about the same rate as component use will increase, leaving dollar value about the same.
- While electronic system and semiconductor costs will continue to decrease over time, there will be a rapid growth in the average electronic content in each vehicle. This ranges from transmission controls and ABS to suspensions and very expensive audio systems (100 watts or more with compact discs). Other areas like telephones and navigation/traffic control will significantly grow into major application rates by the year 2000.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists forecast essentially identical percentages for current estimate and both years, 1995 and 2000. Their respective interquartile ranges are also remarkably close.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in Delphi II but did appear in Delphi I, Delphi III, and Delphi IV. At the time of Delphi III the 5% decrease from the Delphi I forecast was interpreted to mean that cost would drop faster than usage increased. It was assumed that in the intervening years, economies of scale would reduce the individual cost of components. The 5% increase in the Delphi IV forecast for 1990 could then be interpreted as a very substantial overall growth in the utilization of new electronic componentry. This trend of increasing usage of electronics in North-American-produced passenger cars was forecast to continue with the Delphi IV forecast of 20% by 1995. The 5% decrease in this current Delphi forecast for 1995 can be interpreted in a number of ways: the panelists expect the cost of electronic componentry to decrease more rapidly than expected; the non-electric base cost of the vehicle is increasing, thereby expanding the base, or market forces and liability concerns are inhibiting increased application of electronics in passenger cars. Additionally, a number of the panelists' comments directly address this situation and merit serious review.

Fraction Total Vehicle Dollar Value Represented by Electronic Componentry				
Forecast for 1990			Forecast for 1995	
1979 Delphi I	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
15%	10%	15%	20%	15%

STRATEGIC CONSIDERATIONS

Vehicle electronics are forecast to experience a continued expansion of application in North-American-produced passenger cars. Note, however, that expectations have been modestly downgraded from Delphi IV. This is plainly evident in the forecast for 1995, in which electronics were forecast at 15% of total vehicle cost, compared to 20% in Delphi IV. Still, the magnitude is very large and indicative of the significant role electronics will continue to play in tomorrow's passenger vehicles. We suspect that the modest downgrading in expectations of the dollar value represented by electronics is not significantly related to a reduced role for electronics, but rather the sum of a number of factors, including component integration, reduced cost for each electronic function, and better overall systems engineering in the vehicle. In any event, the electronic revolution appears to be continuing unabated in automotive applications.

TECH-64. Of that fraction of electronics cost (in TECH-63), what will be the percentage breakdown among the following electronic components? (Please exclude items such as electrical accessory/drive motors, lighting, etc.)

Electronic Components	Median Response		Interquartile Range	
	1995	2000	1995	2000
Electronic modules/Subsystems	45%	40%	40/50%	40/50%
Sensors/Input Switches	20	20	15/20	15/25
Actuators	15	15	10/15	15/20
Power Switches	6	10	5/10	6/10
MPX Harnesses and Connectors	5	10	5/10	6/10

SELECTED EDITED COMMENTS

- A lot depends on how much integration of controls is done. One computer or multiple computers.
- No trend change here. An equal cost improvement is likely across all these components.
- Fiber optics will be introduced for signal and control circuits, which need to be free of electro-magnetic interference (EMI), or where multi-stranded fiber bundles provide a high level of redundancy on critical circuits.
- Multiplexing likely to have significant application by 2000.
- Sophistication of control systems plus reduced cost for electronic components will dictate.
- Electronic modules/subsystems include radios, amplifiers, instruments. Only sensors and actuators with at least one semiconductor which is integrated into the product.
- Increased use of high-speed multiplexing will allow sensor sharing. Increased functional integration will reduce cost of electronic modules on a percentage basis.
- Power drivers/switches are usually included in modules. They are not mutually exclusive.
- Sensor and actuator costs will not decrease as fast as electronic module costs, so their contribution to total should increase.

MANUFACTURER/SUPPLIER COMPARISON

With the exception of sensors/input switches, the manufacturer and supplier panelists were in general agreement with each other regarding the fraction of electronics costs that these components would represent. With respect to sensors/input switches, the OEM panelists forecast 20% for each of the years 1995 and 2000; the supplier panelists forecast 18% by 1995 and 15% by the year 2000.

TREND FROM PREVIOUS DELPHI SURVEYS

This question is the evolutionary end-product of a series of questions that began with the first Delphi in 1979. While the previous questions are relatively comparable to the present one for the purpose of developing trend data, they are sufficiently different to preclude incorporation into a comprehensive corresponding table. Therefore, these previous Delphi questions and relevant data are presented.

In Delphi I and Delphi III the following question was asked: "What fraction of total vehicle cost will be represented by electronic componentry such as micro-processors, transducers, actuators, etc., in the following years?" The Delphi I forecast for 1990 was 15%. The Delphi III forecast for 1990 was 10%. There was no corresponding question asked in Delphi II.

In Delphi IV this question was refined into two successive questions. These questions with relevant data were as follows.

It is becoming increasingly clear that the U.S. passenger car market is being segmented into two categories: lower technology/high volume (e.g., Cavalier, Escort, Aries) and high technology/lower volume (e.g., Corvette, Mark VII, LeBaron GTS). What fraction of total vehicle cost will be represented by ELECTRONIC COMPONENTRY such as microprocessors, transducers, actuators, sensors, etc., in the following years?

	Fraction of Total Vehicle Cost	
	1990	1995
Lower Technology/High Volume	8%	10%
High Technology/Lower Volume	15	20

Of that fraction of electronics cost, what will be the percentage breakdown among the following ELECTRONIC COMPONENTS? (Please exclude items such as electrical accessory/drive motors, lighting, etc.)

	Percent Electronic Components			
	Lower Technology/ High Volume		High Technology/ Lower Volume	
	1990	1995	1990	1995
Electronic logic modules	40%	30%	30%	30%
Sensors	15	20	20	20
Actuators/Power Switches	15	15	20	20
Input Switchers	10	10	10	15
MPX harness and connectors	10	10	10	10
Other	10	15	10	5
TOTAL— –	100%	100%	100%	100%

STRATEGIC CONSIDERATIONS

Although this question was modestly reformatted making specific comparisons difficult to make, in general the forecasts of Delphi V are consistent with those of Delphi IV. However, on a component basis, various areas of opportunity are rather clearly indicated. Suppliers positioned in general accordance with the breakdown presented should be in a good position, assuming, obviously, their technology, quality, and other factors are commensurate with world-class performance. Also it is important to recognize that the Delphi is a forecast of future trends by experts in the field; it is not a crystal ball, but rather an indicator of the direction these experts think trends are headed.

TECH-65. What percentage of North-American-produced passenger vehicles will employ the following electronic/electrical features in the years 1995 and 2000?

Electronic/Electrical Features	Median Response		Interquartile Range	
	1995	2000	1995	2000
Voice-Activated/Interactive Controls	1%	2%	0/1%	1/5%
Drive-by-Wire (throttle control)	1	5	0/2	2/10
Steer-By-Wire	0	1	0/1	0/5
Collision Avoidance	1	3	0/1	2/5
Electronic Key Entry	5	15	5/10	10/25
Cellular Phones	5	15	5/10	10/25
Rear-View TV	1	2	0/1	1/2
CRT Navigation Systems	1	3	1/1	2/5
CRT Information Systems	2	5	1/2	3/8
CRT Touch Screens	2	5	1/2	1/5
Electronic Digital IP Displays	20	20	15/25	20/30
Electronic Analog IP Displays	20	25	15/20	20/35
Electronic Analog (digitally implemented) IP	20	25	15/20	20/35
Laser-Projected Display	0	1	0/0	0/3
Heads-Up Display	2	5	1/3	3/10
Mechanical IP Display	10	10	2/30	4/20
Electro-Mechanical IP Display	20	20	5/30	10/30

SELECTED EDITED COMMENTS

- Collision avoidance, CRT navigation systems, and CRT information systems will be combined with intelligent vehicle/highway system.
- CRT navigation systems, CRT information systems, and CRT touch screens will be prohibited by law.
- Heads-up displays are not needed in cars and trucks. There is not the response-time problem inherent in military aircraft where the time to look down at an instrument and then refocus on the oncoming terrain or enemy aircraft might prove fatal. It is a gimmick for cars.
- Hope most of these don't make it. Needless functions by and large. The "Ginza" mentality will likely take hold, however. Believe collision avoidance and heads-up display are a good idea. Hope cellular telephone is banned due to safety problem. For example, if engine is running, no phone.
- Some competing technologies will make others not succeed.
- Voice-activated/interactive controls are too hard to remember commands, too much noise (windows, radios)—short-term gimmick.
- "Real" functions, e.g., cellular phones and navigation, will make it. "Toy" functions will fade.
- Only logical voice functions are for car phones.

- Cellular phones should not work while vehicle is in gear. This is a safety issue.
- Collision avoidance will be at least a warning if not an overriding control function. Rearview TV: safety will require more "behind you" knowledge. CRT won't make it; driver is supposed to look at road. Law will control this.
- Drive-by-wire will offer major benefits and will be affordable when added to cars equipped with speed control and traction control. Fail safe must be assured. Collision avoidance needs a sensor technology breakthrough. Speed control and traction control (or drive-by-wire) can do the "actuation" portion of the job.
- Drive-by-wire will be introduced very slowly due to unintended acceleration and liability potential.
- Ergonomics will lead toward more heads-up display technology.
- Heads-up displays probably are not safe if the display interferes at all with vision outside the vehicle.
- Navigation systems do not necessitate a CRT as the only display approach (dot matrix is a viable alternative to CRT). Personality features (seats, mirrors, etc.) will exploit electronic key technology. What about remote entry, electrochromic glass, etc?
- Voice-interactive controls are unnecessary, too expensive, and too fraught with problems. Cellular phones are just a luxury option and a safety problem; only aftermarket. CRT navigation systems require too much infrastructure in the community to be realizable before late in century. Flashing and changing digital displays will eventually give way to less distracting analog units after "gimmick" wears off. Use of digital will be only for a few selected parameters on demand. Steer-by-wire safety questions will limit early use. Back-up systems will raise costs and thus limit eventual penetration.

MANUFACTURER/SUPPLIER COMPARISON

The following table illustrates differences between manufacturer and supplier forecasts. Note that even where differences exist, they are (with only two exceptions) within 1–5%. This demonstrates a remarkable degree of consensus between the two groups on the percent application of these features.

Electronic/Electrical Features	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Steer-by-Wire	*	*	2%	1%
Cellular Phones	*	*	15	20
Rearview TV	0%	1%	*	*
CRT Information Systems	2	0	*	*
Electronic Analog IP	*	*	25	20
Mechanical IP	15	5	10	5
Electro-Mechanical IP	20	15	20	10
Laser-Projected Display	*	*	2	1

*No difference between forecasts.

TREND FROM PREVIOUS DELPHI SURVEYS

As is apparent in the following table, there is a dramatic reduction from the Delphi IV forecasts for the percent market penetration of the listed electronic/electrical features.

Electronic/Electrical Features	Forecast Usage by 1995	
	1987 Delphi IV	1989 Delphi V
Voice-Interactive Controls	10%	1%
Drive-by-Wire	5	1
Collision Avoidance	5	1
Electronic Key Entry	15	5
Cellular Phones	15	5
Laser-Projected Display	10	0
Heads-Up Display	8	8
Navigation/Information Systems	10	*
CRT Dashboard Displays	5	*
On-Board Map/Locational Readout	10	*

*These features were surveyed in Delphi IV. Although not precisely comparable to features surveyed in this Delphi, they are sufficiently comparable to warrant analysis in trend data.

STRATEGIC CONSIDERATIONS

The percent application for a wide range of electrical/electronic features are addressed in this question. In most of the cases, expectations through the year 2000 are relatively modest. Although there is strong support for electronically based instrument panel (IP) displays, including electronic digital, electronic analog, electronic analog visually implemented, and electro-mechanical, the progressive application of these technologies must be carefully tracked. Customer enthusiasm and acceptance as well as cost reduction associated with higher-volume use could dramatically accelerate levels of application in the next decade.

TECH–66. On a dollar-value basis, what is, and what will be, the vehicle manufacturer's make/buy ratio for electronic hardware (including sensors and actuators) for the years 1995 and 2000?

Vehicle Manufacturer	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
PERCENT MAKE						
GM	70%	70%	70%	70/70%	60/75%	60/75%
Ford	50	50	50	50/50	40/50	40/50
Chrysler	40	30	30	30/40	30/40	25/40
Japanese*	20	25	30	20/30	20/30	20/30
PERCENT BUY						
GM	30%	30%	30%	30/30%	25/40%	25/40%
Ford	50	50	50	50/50	50/60	50/60
Chrysler	60	70	70	60/70	60/70	60/70
Japanese*	80	74	70	70/80	70/80	70/80

*Japanese companies in North America (including joint ventures).

SELECTED EDITED COMMENTS

- Far East suppliers will take a significant part of the business in electronics.
- Integration of electronic functions and the incorporation of an electronic vehicle architecture will result in more "Make."
- Many new electronic-related breakthroughs will come from the Far East; mostly from non-automotive companies.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in unanimous agreement regarding the OEM make/buy ratios for electronic hardware for all manufacturers and years queried.

TREND FROM PREVIOUS DELPHI SURVEYS

Current Delphi V forecasts appear to be consistent with previous Delphi IV forecasts for electronic hardware make/buy ratios. Although the Delphi IV question did not specify a year (assuming a 1986–1987 survey time-frame for Delphi IV), the current Delphi V forecasts (late 1988–1989) for the years 1995 and 2000 are consistent with a gradual yet increasing trend of percent-make for electronic hardware by the OEMs. The Delphi IV question and relevant data are as follows.

On a dollar-value basis, what will be the vehicle manufacturer's make / buy ratios for ELECTRONIC HARDWARE (including sensors and actuators)?

	Median Response	
Vehicle Manufacturer	Percent Make	Percent Buy
General Motors	60%	40%
Ford Motor Company	40	60
Chrysler	25	75
Japanese companies in U.S. (including joint ventures)	15	85

STRATEGIC CONSIDERATIONS

The make/buy ratio of OEM electrical/electronic purchases is expected to closely parallel perceptions of the manufacturers' levels of vertical integration. In most cases, stability is envisioned through the next decade, although in the case of Chrysler, a modest reduction in the percentage of electronic hardware produced in-house is possible. A modest increase in percent internally produced by Japanese companies is also expected. The overall ratio of in-house sourcing, compared to Delphi IV, is forecast to increase slightly. This is due, perhaps, to increasing emphasis on the part of all vehicle manufacturers to integrate electronics at a vehicle-systems level. It is apparent that suppliers are also expecting to increase their electronic business at the subsystem level. To do so they will have to increase their systems capability beyond the selling of discrete components. Clearly, the high level of overall outside purchases expected by the manufacturers suggest that considerable opportunities are available to the electrical/electronic supply base. However, because of the rapid rate of technological development/change within this very high-tech and potentially very profitable area, today's winner may be tomorrow's loser.

TECH-67. In North-American-produced passenger vehicles, what fraction of the cost of the following major vehicle systems will be represented by electronic components?

Vehicle Systems	Electronic Components: Percent of Total Cost			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Engine/Powertrain	15%	15%	10/20%	10/25%
Transmission/Drivetrain	10	15	5/15	10/20
Driver Information	50	70	30/80	50/85
Safety	15	20	5/25	10/35
Audio & Other Entertainment Systems	85	90	75/97	75/100
Convenience Control	50	50	20/70	30/80
Vehicle Motion Control (anti-skid suspension, four-wheel steering)	20	30	15/50	20/60
Other Vehicle Systems	10	10	2/25	5/35

SELECTED EDITED COMMENTS

- Percent will go down due to electronic cost reduction at a greater rate than mechanical systems.
- Taking into consideration downward price spiral of electronics due to economies of scale and higher level integration. There should be no significant change in percent between 1995 and 2000 (more features for the same dollar amount).

MANUFACTURER/SUPPLIER COMPARISON

The following table represents the differences between OEM and supplier panelists on the fraction of the cost of major vehicle systems represented by electronic components. In a number of the vehicle systems surveyed, the supplier panelists expect a higher percentage of the costs of these systems to be represented by the cost of the electronics incorporated in these systems.

Vehicle Systems	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Engine/Powertrain	15%	15%	15%	20%
Driver Information	60	40	70	70
Safety	10	15	15	30
Audio/Entertainment	80	90	85	90
Convenience Control	40	50	50	70
Vehicle Motion Control	20	50	25	60

TREND FROM PREVIOUS DELPHI SURVEYS

For the most part, the forecasts for 1990 presented in Delphi III are consistent with forecasts for 1990 in Delphi IV. The 1992 Delphi III forecasts are similarly consistent with Delphi IV projections for 1995. Although categories in this Delphi are divided into more specific subject areas, a comparison of the data from two previous Delphis reveals a consistency in the established trend for each category.

Passenger Car Systems	Electronic Components: Percent of Total Cost			
	Median Response			
	Delphi III 1990 Forecast	Delphi IV 1990 Forecast	Delphi III 1992 Forecast	Delphi IV 1995 Forecast
Comfort, convenience, entertainment	40%	40%	40%	50%
Engine/transmission	15	10	15	15
Chassis/suspension	N.A.*	5	N.A.	15
Safety	10	5	10	10

*Data not available.

STRATEGIC CONSIDERATIONS

This question is a continuation of inquiries in Delphi III and Delphi IV regarding the percent of the cost of major vehicle systems represented by electronic components. Although this question has been reformatted and these responses are not precisely comparable to previous ones, a qualitative consistency can be observed between the past and present Delphi forecasts.

Electronics, on a cost basis, are expected to continue to be an important factor in most major vehicle subsystems. In several of these subsystems, e.g., driver information, entertainment, and convenience, the percent cost of the electronic content is expected to be substantial. In practically every vehicle system, the application of electronics technology is expected to increase in the years ahead. However, the rather wide interquartile ranges evident in some of the forecasts indicate a considerable degree of uncertainty exists regarding future percent electronics costs.

Some of these subsystems can be considered relatively technologically mature; whereas other systems, such as transmissions, are just beginning to incorporate new and innovative electronic advances.

A note of caution is advisable with regard to vehicle electronics. A significant percent of present warranty problems can be traced to electronic or electrical malfunction. This seems to be prompting a thoughtful review of some traditional technologies that were seemingly destined for extinction. There is at least a suggestion that, updated and properly implemented, some of these technologies may become competitive with electronics. In a sense this may be somewhat parallel to what has developed in the competition between steel and plastics. The threat posed by the increasing utilization of plastics stimulated the steel industry to develop and introduce new and improved steel processes and products and thereby dramatically enhance their competitive positions. While it would appear that electronics will play an increasingly important role in the future, there is at least a hint that some of the traditional control systems are not being as readily dismissed as they had been just a few years ago.

TECH-68. What percent of North-American-produced passenger vehicles will utilize at least one major multiplexed (MPX) electrical subsystem by 1995 and 2000?

Passenger Cars with:	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
At least one major multiplexed electrical subsystem	1%	7%	20%	0.5/1%	5/10%	15/40%

SELECTED EDITED COMMENTS

- Current systems are very limited: diagnostics and very limited/very slow data transfer. Future systems will include more and faster data sharing.
- MPX will appear on only the most complex models.
- Other technologies are competing with multiplexing.
- Partial multiplexing will attain much higher use than full-vehicle multiplexing. This answer "partial" but significant.
- Still problem of cost difference between discrete wiring and multiplexing. Fiber optic cable cost will determine acceptance.
- Multiplexing will allow more functional integration (connector limitation) and control the size of the wiring harness. Net result is vehicle cost saving and reliability improvement.
- Multiplexing is and will continue to be a cost penalty to the base vehicle. The control system electronics cost is not offset by the wire reduction or reliability increase.

MANUFACTURER/SUPPLIER COMPARISON

Although the manufacturer and supplier panelists are in agreement as to the current estimate of North American passenger vehicles that utilize at least one major multiplexed electrical subsystem, as illustrated in the following table, there was disagreement on the forecast for years 1995 and 2000.

Passenger Cars with:	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
At least one major multiplexed electrical subsystem	10%	5%	22%	20%

TREND FROM PREVIOUS DELPHI SURVEYS

In 1984, Delphi III panelists forecast that by the year 1990, 10% of U.S.-produced passenger cars would employ multiplexed, common-bus wiring to some extent rather than the conventional loom-type harness design. This was double the Delphi IV forecast of 5% by 1990. For 1995, the Delphi IV forecast was 20%, which at that time seemed in reasonable accord with the Delphi III projection of 20% for 1992. For reasons discussed in *Strategic Considerations*, the current forecast of 7% for 1995 represents a considerable diminution from previous forecasts. It is of interest, however, to note that in 1982, only 1% of Delphi II panelists expected that multiplexing would see broad application by 1990.

Passenger Cars with:	Forecast for 1995			
	Median Response		Interquartile Range	
	1987 Delphi IV	1989 Delphi V	1987 Delphi IV	1989 Delphi V
Multiplexed Electrical Systems	20%	7%	10/25%	5/10%

STRATEGIC CONSIDERATIONS

It would appear that a more mature understanding of the role of multiplexing is developing within the automotive industry. Expanded use of multiplexing is envisioned to occur during the 1990s. In fact, the increasing use forecast from 1995 to the year 2000 is substantial. However, as evidenced by the relatively broad interquartile ranges, there remains a significant degree of uncertainty regarding the actual magnitude of that role.

Obviously, areas of the vehicle with challenging packaging problems or a high density of electrical wiring are primary candidates for multiplexing. Suppliers of components impacted by a trend towards multiplexing—for example, connector and wiring suppliers—should proceed with caution. As we understand it, a major fraction of warranty problems are related to electrical/electronic factors, and about half of those are associated with poor connections or interfaces between various elements of various systems. If these problems are not resolved, multiplexing could be viewed as the solution in the present quality-conscious environment. Of course, there remain important reliability issues with current multiplexed systems that must be addressed.

TECH–69. What percent of North-American-produced passenger cars will utilize multiplexing in the following subsystems?

Subsystems	Percent Utilizing Multiplexing			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Door interfaces for power controls (power windows, seats, door locks, mirrors, etc.)	5%	20%	2/10%	10/40%
Lighting controls (headlamps, tail lights, turn signals, and other interior lighting)	5	15	2/10	7/25
Steering column wiring	5	20	2/10	10/30
Entertainment	5	20	2/10	5/30
Vehicle information/instrument panel (IP) functions	10	20	3/20	15/50

OTHER single responses were: chassis control, control systems, ABS, diagnostics, suspension and steering, engine/suspension.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in reasonable agreement on the percentage of multiplexing for many of the subsystems. The following table represents those subsystems where modest differences were significant.

Subsystems	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Lighting Controls	*	*	15%	20%
Steering Column Wiring	5%	3%	20	15
Entertainment	5	2	20	10
Vehicle Information	10	5	*	*

*No significant difference in forecasts.

TREND FROM PREVIOUS DELPHI SURVEYS

In Delphi IV the following question was asked: "Which electrical systems will be the first to use multiplexing?" The five subsystems surveyed in this Delphi were the five major subsystems suggested by Delphi IV panelists. Door interfaces for power controls and lighting controls received the largest percent of Delphi IV panelists' responses, with 44% and 34%, respectively. The remaining subsystems received between 12–18%.

STRATEGIC CONSIDERATIONS

Multiplexing in automobiles is a much-discussed technology that has been somewhat slow in automotive application. However, as the cost effectiveness of multiplexing improves it is clear there will be increased applications throughout the entire vehicle.

Multiplexing offers the potential to replace the existing harness with a few wires. Typically, an automotive multiplex system would consist of a wire for carrying power to each electrical component (e.g., motors or lights) and a separate wire linking a controller with a special coded receiver for each switched load. By transmitting a unique code to a given receiver, it is possible to switch on the related electrical device. In this way the very complex, heavy, and expensive wiring harness which is presently used for switching electrical devices is replaced with a pair (or at most three) wires, resulting in considerable weight savings to send controls. Similarly, the wiring required to send signals from one electronic subsystem or component to another can be replaced by a multiplex link. The savings in weight and harness complexity provided by multiplexing are strong motivation for its introduction. On the other hand, the perceived cost/benefit for multiplexing continues to inhibit its application.

The responses to this question support the notion that multiplexing will be introduced as a partial system and will only gradually evolve to increase its fraction of the vehicle electrical system.

TECH-70. What percentage of multiplexed systems will utilize the following techniques?

Techniques	Multiplexed Systems: Percent Application	
	Median Response	Interquartile Range
Wire Control Bus	75%	50/95%
Fiber-Optics Control Bus	25	5/50

SELECTED EDITED COMMENTS

- Twisted pairs of wires will dominate initially, perhaps supplemented by fiber optics.
- Speed/capacity inherent in fiber optics are not needed unless and until many more things are put onto a multiplexed system than are now being contemplated.

MANUFACTURER/SUPPLIER COMPARISON

A comparison of OEM and supplier forecasts reveals a remarkable degree of disagreement regarding the application of multiplexing systems.

Multiplexed System	OEM	Supplier
Wire Control Bus	90%	50%
Fiber-Optics Control Bus	10	50

TREND FROM PREVIOUS DELPHI SURVEYS

In Delphi IV the techniques for multiplexed systems were described somewhat differently. Although there is different wording between the two Delphis, the forecasts of the two groups of panelists appear to coincide. These results from Delphi IV are presented in the following table.

Multiplexed System	1987 Delphi IV
Electrical Signals/Smart-Power Switches	74%
Fiber Optics	21
Other: Laser/Infrared (IR)	5

STRATEGIC CONSIDERATIONS

A major competition between the control links for multiplexed systems is evident. At this point the preferred data bus will utilize wire rather than fiber optics. However, if lower-cost and higher-quality interfaces between the electrical-optical components are developed, the competition could become interesting. The very broad interquartile range and significant differences between manufacturer and supplier forecasts suggest that this will be an area of considerable uncertainty for the next few years.

TECH–71. Do you foresee on-board circuits that for reliability or safety considerations will be hard-wired instead of multiplexed? Please comment.

Hard-Wired Circuits vs. Multiplexing	Percent of Panelists
Continuation of hard-wired on-board circuits	71%
Multiplex technology reliable and sufficient without hard-wiring	29

The circuits/functions that were forecast to be hard-wired are as follows:

Circuits/Functions to be Hard-Wired	Percent of Panelists
Brake function/ABS	45%
Steering control/Electronic power steering	24
Safety functions	24
Throttle control/Drive-by-wire	21
Powertrain/Engine controls	21
Lighting	10
Suspension systems	7
Ignition circuits	7

The diversity of responses necessitate the inclusion of *Representative Responses*. These are divided into a *YES* group (continuation of hard-wired on-board circuits) and a *NO* group (favoring multiplexing over hard-wired circuits or combination of both functions for complementary functions).

YES HARDWIRE: REPRESENTATIVE RESPONSES

- Some systems may revert to mechanical for cost, reliability, or repairability reasons.
- Those associated with brakes and fuel systems.
- Before 2000 all safety-related circuits will probably be hardwired.
- Drive-by-wire, some ABS, high safety requirement will require redundancy.
- Expect a transition. Hardware for experience—move to multiplex. Similar to aircraft industry learning process.
- Systems which need to operate without the ignition switch or a key control system—door lock, anti-theft device, emergency lights, etc.
- Fast signals such as ignition pulses, fuel injection pulses, and ABS speed sensor inputs.
- Real-time control usually requires a faster data rate than multiplex systems can deliver reliably.
- Brake/steering or airbag will remain hardwired.

- High-speed, control-critical systems, e.g., anti-wheelspin with ABS and drive-by-wire.
- I estimate only 15% to 20% vehicle harnesses will be multiplexed. The remainder will be hardwired. However, reliability and safety are only two reasons. Other reasons include flexibility in vehicle design, failure to adopt standard protocols, and cost.
- Safety reasons will control several circuits.
- Those areas that require absolute data transmittal will still be hardwired.
- Vehicle steering, braking, and throttle control circuits will probably be hardwired.
- Critical powertrain and safety functions will be hardwired to sensors and actuators. The modules will also be linked to the network for information/data exchange. Yes, for controls of safety critical functions in steering and braking.
- At some point in time MPX circuits will be at least as reliable as hardwired circuits. Controls requiring dynamic response, including engine and powertrain, active suspension, ABS, all-wheel drive, and four-wheel steering, will be hardwired. Lighting, static trim, and others not requiring time-critical response will be multiplexed.
- Due to product warranty and product liability concerns.
- Throttle-by-wire; failsafe ABS; electric power steering. In general go-steer-stop functions will remain hardwired in foreseeable future.

NO HARDWIRE: REPRESENTATIVE RESPONSES

- I think it can be implemented just as safely with multiplexing and some redundancy.
- Reliability of electronic modules will increase beyond today's excellent record. Advancement of connectors will result in negligible disconnects. End-of-line test will further ensure negligible reliability concerns.
- Reliability will be high—and proven. Systems will be self-checking with failsafe shut-down modes.
- If failure mode management is properly done, there should be no reliability or safety difference between "hardwired" and multiplexed.
- With the evolution of multiplexing there will be very high reliability and/or the capability to implement redundancy in a cost-effective manner.
- Not necessarily. Both hardwired and multiplexed will be present on same vehicle, for complementary functions.
- Not necessarily. Can have alternate/simultaneous back-up multiplexing sources with comparators at both ends.
- I believe multiplex technology will be more reliable than plugs and wires.

STRATEGIC CONSIDERATIONS

There is still strong support for hard-wire technology in a number of critical vehicle systems. Multiplexing, however, is beginning to develop some support, although we suspect that it will still be some years before confidence in multiplexing is sufficient to stimulate increased use. As with any new technology, safety and reliability concerns are very evident.

TECH-72a. Do you foresee that vehicle electrical-system voltages will be increased over the 12-volt level by the year 2000?

Increased Voltages	Forecast for the Year 2000
Yes	58%
No	42

SELECTED EDITED COMMENTS

- 2000 is too early for 24-volt system. However, it will happen because of the advantages.
- Batteries may limit the base voltage to 12 volts but we will then see expanded use of dual-voltage systems.
- Efficiency improvement for electric motors/actuators.
- Greatest cost savings will result with extended standardization of current systems.
- Higher voltage lamps raise durability issues.
- Probably a 48-volt system.
- Will be required because total vehicle power consumption will exceed 2 kilowatts. Present 12-volt alternator technology cannot produce 2 kilowatts, e.g., active suspensions, electric steering, electric air-conditioning, heated windshields/side glass, etc.
- Voltage increase required as total electrical power usage is increased.
- Selectively used for specific functions. Storage voltage will remain 12 volts. Requires industry standardization; not likely before 2000.
- The ever-increasing vehicle electrical/electronic load will drive the need for vehicle load shedding or increased vehicle-system voltage, perhaps as high as 48 volts.
- There are some unique opportunities for 24-volt systems.
- There will be a move to increase system voltage but it'll be averted by better efficiency, negating the need for higher voltages.
- Why change?
- Twenty-four-volt systems are possible, not too likely though.
- Twenty-four-volt systems for 25% of vehicles by 2000.
- Forty-eight volts reduces power losses in transmission by 75%.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturers and suppliers took opposite positions on the need to increase electrical system voltages. Their responses are as follows.

Increased Voltages	Forecast for 2000	
	OEM	Supplier
Yes	65%	47%
No	35	53

STRATEGIC CONSIDERATIONS

Although at present there is still a high level of interest in the conventional 12-volt system, with growing electrical demand in future vehicles, a major shift is expected in system voltage. It would appear that from a practical standpoint we may eventually see dual-voltage systems, e.g., 12 and 24 volts or 12 and 48 volts, either of which could optimize the relationship of the power supply to the various functions performed in the vehicle. Higher-power-demand functions would benefit from a high-voltage source, whereas some of the traditional needs, such as lamps, function better with lower voltage. Such a change could have a significant effect on a number of key suppliers to the automotive industry. Motors, wiring harnesses, batteries, alternators, and, in fact, most of the electrical components would be effected. If this change is coupled with an increased use of multiplexing, we could be seeing profoundly different electrical systems within the next ten years.

TECH-72b. If yes, what voltage level and what maximum current do you expect in the year 2000?

Yes Response:	Voltage Level		Maximum Current	
	Median Response	Interquartile Range	Median Response	Interquartile Range
Forecast for 2000	24 Volts	24/48 Volts	100 Volts	70/100 Volts

SELECTED EDITED COMMENTS

- Maximum current depends on electronic-system load-management.
- The system will likely be dual-voltage system that has both 12 volts and 24 volts available.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in accord regarding expectations for voltage level and maximum current for the year 2000.

STRATEGIC CONSIDERATIONS

There are several issues involved in changing voltage levels. A slight reduction in vehicle weight and an increase in power supply efficiency can be achieved by raising power supply voltages and using smaller-diameter wires in the harness. However, the storage battery must have more cells than for the present 12-volt system. If the trend to increasing overall electrical power requirement continues, there may be little choice but to pursue this course.

Virtually all on-board electrical systems are affected by this change. All interior and exterior lighting must be changed to operate at the higher voltages. All motors and solenoids must similarly be redesigned. Electronic systems can (in principle) be operated at higher voltages than the present 12 volts by simply changing the voltage regulator circuitry. It would appear likely that dual-voltage systems, 12/24 or 12/48, could be used to optimize the interface with various vehicle electrical/electronic components.

Clearly a change in voltage will require some modification to virtually all electrical/ electronic systems. Such a change does not come without cost. Nevertheless the majority of panelists expect to see a change to higher voltages in the next decade.

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