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TECHNOLOGY
MATERIALS

DELPHI IV FORECAST AND ANALYSIS OF THE U.S. AUTOMOTIVE INDUSTRY THROUGH 1995

TECHNOLOGY

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For information, address:

Office for the Study of Automotive Transportation
The University of Michigan
Transportation Research Institute
2901 Baxter Road
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David E. Cole, Director
Office for the Study of
Automotive Transportation

Richard L. Doyle,
Senior Research Associate
Office for the Study of
Automotive Transportation

FOREWORD

INTRODUCTION TO THE STUDY

Delphi IV is a detailed presentation and analysis of data provided by three separate panels of automotive executives, managers, and engineers who are expert in technology, materials, and marketing. This report, published in three volumes, is the fourth in a series of in-depth studies of long-range automotive trends that began with Delphi I in 1979 and continued with Delphi II in 1981 and Delphi III in 1984.

We have performed the functions of data collection, data reduction, editing, and reporting, and analyzed the results. However, we emphasize that the forecasts are not ours but those of the participants. This is a consensus industry forecast of itself—and many of the experts are in positions where they can make their forecasts come true.

We take pride in our efforts to report Delphi IV forecasts, but no credit. The honor goes to the executives, managers, and engineers who provided them. Because of their source, we consider these to be the most authoritative and dependable automotive forecasts available.

THE DELPHI METHOD

General Background

This study is based on the Delphi forecasting process, in which panels of experts consider the issues under investigation and make predictions about future developments. Developed for the U.S. Air Force by the Rand Corporation, Delphi is a systematic, iterative method for forecasting based on independent inputs from a group of experts. Its objective is to measure the degree of consensus among a panel of experts regarding future events.

The Delphi method relies on the judgment of knowledgeable experts. This is a strength (in contrast to purely numerical projections) because predictions that require policy decisions are strongly influenced by personal preferences and expectations, in addition to more quantitative factors. The Delphi results reflect these personal factors. The respondents whose opinions are recorded in this report are often in a position to at least partially make their predictions come true. Even if subsequent events eventually force a change in direction the primary concern of this report is to learn what that direction is now.

Process

The Delphi method uses repeated rounds of questioning (accompanied by the responses of peers to earlier rounds) to take advantage of grouped inputs while avoiding biasing effects so 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 discussion. 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 interests, 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. Norman C. Dalkey, "The Delphi Opinion." Memo RM-588 PR, p. 14, Rand Corporation, 1969).

Panelists

In the Delphi method, panelists are not made known to each other. Their anonymity prevents attaching a specific opinion to any individual. Among other advantages, this enables respondents to feel comfortable in revising their previous opinion after seeing new information submitted by other panelists. All participants are encouraged to comment on their own forecast and on group results, and that information is furnished the participants in the next round. The procedures reduce the effects of personal objectives (such as the desire to win an argument) and help the panelists to remain focused on the question, positions, and comments at hand.

Presentation of Results

Numerical results are shown as medians, a measure of central tendency that mathematically summarizes an array of judgmental opinions while discounting extremely high or low estimates.

Uncovering differences of opinion is one of the major strengths of the Delphi method. Unlike some survey methods, where differences of opinion among experts are buried in averages, Delphi exposes such differences through the presentation of the interquartile range (IQR). A lack of consensus so demonstrated is little comfort to an individual or firm looking for planning guidance, but it is better to know the truth than to be misled.

Sample Size

Delphi surveys are undertaken with sample sizes that may appear small when compared to the relatively large numbers needed to provide accurate results in a probability sampling of an extensive universe. Delphi is by design not a random technique, however, and should not be assessed with the measures used to evaluate probability surveys. Delphi respondents are carefully selected, not chosen at random, and the universe of qualified automotive respondents is so relatively small that our sample approaches a census.

PANEL CHARACTERISTICS

The heart of a Delphi survey is the careful selection of expert respondents. Neither the Delphi process nor any other research method will result in meaningful predictions unless contributors are truly expert. The selection of such experts for the Delphi survey is made possible by close ties of long standing between University of Michigan faculty and staff and representatives of the automotive industry. The opinions of more than 250 experts in the automotive industry are the basis of this Delphi IV forecast.

Lists of prospective expert panelists were developed: one each for Marketing and Materials, and three for Technology (Body/Chassis, Powertrain/Drivetrain, and Combined). Each prospect was evaluated by a committee of persons with long experience and wide contacts in the automotive industry. Many of the panel members are known personally by one or more members of the committee. Panel members were selected who occupy an automotive industry position dealing with the topic being surveyed and are known to be deeply knowledgeable and broadly experienced in the subject matter.

Panels include some respondents employed with motor vehicle manufacturers and others working for their suppliers of components, parts, and materials. It is common within the industry and convenient here to refer simply to "manufacturers" and "suppliers."

Panel members and their replies are kept anonymous. However, panelists were asked to mail in a business card to enable us to send them follow-up questionnaires. These cards were used to determine the following panel characteristics: approximately 25% of the Technology panelists were presidents or vice presidents; 40% were directors and managers; 24% were engineers, and included chief, assistant chief, and staff. The others were technical specialists. About 45% were employed by vehicle manufacturers, 50% by component and parts suppliers, and 5% by materials suppliers.

Further, the Technology Panel was divided into three sub-panels: Body/Chassis, Powertrain, and a Combined group. The Combined panel consisted of engineering experts who wanted to respond to all technology questions. The panel was subdivided in order to minimize the complexity and length of the questionnaire. For example, the Body/Chassis panel was asked questions directly related to body/chassis technical trends but not powertrain issues. A number of questions were common to all panels. These included questions related to vehicle electronics, energy economics, sourcing, and manufacturing. In the final tabulation of results all data has been combined.

The Marketing panel was made up of 30% presidents, chairmen, CEOs, and vice presidents; 30% were managers, and 16% were directors. The remainder were marketing and planning specialists. Twenty-one percent were employed by vehicle manufacturers, 60% by component and parts suppliers, and 19% by materials suppliers.

Among Materials panelists, 77% were general managers, vice presidents and directors, 7% engineers, and the others consisted of technical, marketing, and planning specialists. Employment was 22% by vehicle manufacturers, 26% component and part suppliers, and 52% materials suppliers.

HOW TO USE THIS REPORT

In the course of their planning activities, industry executives make extensive use of quantitative analyses and forecasts. But, because of major unknowns in the future environment of the industry, those executives also rely heavily on judgment. The Delphi procedures measure the results both of numerical analyses and of judgmental factors being exercised by the experts.

How useful are the Delphi forecasts? A factor to consider is that the experts whose opinions constitute the forecasts are in positions within the automotive industry where they have the responsibility, authority, and resources to make at least some of their predictions come true.

No matter how uncertain it is, the automotive future must be anticipated. With lead times up to five years for vehicles, and longer for some facilities, manufacturers had to begin taking action years ago in order to produce vehicles today. If a forecast reflects a high degree of consensus, it is a path the industry is following. Knowing this provides you with planning lead time—time that could be used either to plan to mesh with the forecast or to attempt to change the factors that are the basis for the forecast. In many cases it may be possible to change the future before it arrives.

For suppliers and others interested in the automotive industry, these Delphi forecasts establish the best planning base we know. They provide lead time to move with trends or to alter events and change undesirable trends.

Delphi forecasts are primarily strategic planning instruments—not the only ones, but part of a collection that should be used in the planning process. The value of a Delphi forecast is measured by how well it helps you and your organization to succeed in the years ahead.

Note: The best method to locate individual items of interest is to consult the *Index of Questions Listed by Topic* at the end of this document.

PRESENTATION OF STUDY RESULTS

The many forecasts assembled in Delphi IV may not always appear to be related to each other, but generally they are. Readers should realize that the automotive industry and its products represent a unified system. It is, of course, greatly complex, but an understanding of the interrelations between parts will lead to the most effective long-range planning.

This complexity explains the broad range of the U-M Delphi forecasts. For example, unit sales of cars and trucks are forecast in detail, and therefore, dozens of underlying trends that drive sales and production are covered, including fuel prices, market shares, supplier relations, and vehicle quality.

Numerical Tables

When the question asked panelists 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 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 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 median of 40% (the same as in the preceding example) but an interquartile range of 20–70%, indicating little consensus among the respondents or substantial uncertainty with regard to the future. This would be a warning that the median forecast of 40% may not have a high predictive value—which is in itself valuable information.

Interpretation of IQR

The interquartile ranges are a key to maximizing benefits from a Delphi study. A close consensus, as indicated by a tight interquartile range, is encouraging in the sense that it indicates agreement among experts. Such a consensus does not "prove" the forecast is necessarily going to come true; a sudden change in the international scene could lead all respondents to agree on a different set of answers. What a consensus does indicate, however, considering the expert knowledge and key position of the respondents, is that anyone whose interests are tied to the future of the U.S. automotive industry can make plans based on the knowledge that, until new factors prevail, industry plans and actions at all levels in vehicle manufacturer and major supplier companies will probably reflect the consensus. But it should always be remembered that even the best forecasts are trend predictions about which cyclical variations are almost a certainty.

A broad IQR suggests that the forecast should be viewed with less confidence and a high priority be placed on closely following the subject under consideration in order to keep alert to significant developments.

Respondents' Comments

In a Delphi survey, respondents are encouraged to write in comments—to explain their forecast and to convince other respondents to change their positions. Many of these comments are shown in this report. Redundant comments are excluded. These replies may be important clues to future events or trend changes that are not apparent in the numerical data. An individual panelist may know something unique and special that planners should carefully consider. However, readers should be careful not to overrate the comments. 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. Of course, one point in collecting and displaying comments is that—perhaps—one or more of them should lead to contrary action. In the final analysis, it is up to the reader to decide.

Discussion

Narrative discussions are presented to highlight future trends and the interquartile ranges of the survey results.

Comparison of Vehicle Manufacturers and Supplier Panelists

For competitive reasons the manufacturers try to maintain secrecy regarding their forward plans, and it might be thought that their representatives know more than others about the automotive future. Offsetting this, the manufacturers source from 30 to 70 percent of each finished product with suppliers and work together closely with few secrets between them. However, the size (hundreds of suppliers) and complexity of the information network can prevent optimal information transfer. Therefore, our analysis includes a comparison of answers from manufacturer and supplier respondents to determine if there are significant differences of opinion.

Trend From Previous Delphi Surveys

A single Delphi survey is a snapshot of time: it collects and presents the opinions and attitudes of a group of experts at one point of time. But the market and business environment change; better information becomes available as we move closer to the forecast period. Data from previous Delphis are presented to track these changes in opinion. Significant changes (as in forecasts of fuel prices) should prompt the reader to consider the environmental drivers behind the forecast.

Strategic Considerations

Based on the replies to the question being discussed, other Delphi IV results, earlier Delphi studies, and OSAT's extensive interaction with the automotive industry over several years, inferences are drawn as to major developments and their impact on the industry.

Reference To Other Delphi IV Sections

Where appropriate, we have crossed-referenced discussions or numerical tables in other Delphi IV volumes. This allows the reader to gain input from a different perspective of expertise. It is important that all dimensions—marketing, engineering, manufacturing, and distribution—be considered in developing a business strategy.

CONTENTS

EXECUTIVE SUMMARY

The Technology volume of The University of Michigan *Delphi IV Forecast of the U.S. Automotive Industry Through 1995* suggests that fast-paced changes are expected in automotive technology. During the same period, trends of vehicle size and weight suggest far more modest reductions than anticipated in prior Delphi studies. Major areas of the vehicle which will experience substantial change include the engine and overall drivetrain, and body and chassis, as well as such subsystems as entertainment and safety. Electronics are expected to play a far more prominent role in future vehicles and be a key part in the increased application of innovations such as anti-lock braking systems, four-wheel steering, active suspensions, improved diagnostics, and a host of other features.

In the 1987 Delphi Technology forecast, panels were divided into three groups: powertrain/drivetrain, body/chassis, and a combined panel. The results presented are an aggregate of all three panels. Key technical areas that were explored include: engines, transmissions, body/chassis characteristics, electronics, fuels and lubricants, materials, and manufacturing issues, as well as a number of competitive factors such as trends in off-shore sourcing and expected energy prices.

Substantial changes are expected with the redesign of a significant fraction of today's engines (Tech-33) and the increased use of such components as aluminum cylinder heads and blocks (Tech-39). Trends in engine displacement and configuration (Tech-31 and Tech-32), and new technological features (Tech-37) are explored as are electronic fuel injection (Tech-44), advanced ignition systems (Tech-45), and a variety of internal technology such as three- and four-cylinder heads and fastburn combustion (Tech-37). It is clear that engines will be built with a higher level of technology and manufacturing precision.

Transmission quality is expected to be improved substantially. Transmission type and feature content are forecast (Tech-58 through Tech-60). The continuously variable transmission (CVT) may begin to emerge in the later part of the next ten-year period, assuming significant problems are resolved (Tech-61 and Tech-62).

Vehicles will continue to be downsized and downweighted, although the reduction is far less than anticipated based on earlier Delphi forecasts (Tech-4). The unibody, or integral body/frame design, will be the primary construction technique; however, use of the space frame is expected to grow significantly (Tech-13 through Tech-15). The distribution of materials in the vehicle (Tech-6) suggests that steel will remain the dominant automotive material; however, substantial growth in plastics and aluminum use are forecast. The competitive battle between plastics and steel is likely to be intense (Tech-16 through Tech-18). Significant developments are anticipated in the chassis area, including modest application of four-wheel drive in passenger cars (Tech-25), and a host of features such as anti-lock braking, electronic power steering, and four-wheel steering (Tech-19, Tech-21, Tech-22, and Tech-24).

Fuel economy will continue to be an important factor in directing future automotive design (Tech-2), and generally will improve during the next ten years (Tech-3). Important issues with regard to both fuels and lubricants (Tech-47 through Tech-56) are included in the discussion.

Electronics will play a prominent role in practically every vehicle system. The percentage of overall vehicle cost represented by electronics is expected to expand significantly (Tech-64, Tech-65, and Tech-67). A substantial improvement in diagnostic technology is expected (Tech-68) and expanded use of such advanced technologies as multiplexing (Tech-70 through Tech-73) is forecast. A significant number of electronically-based features will be introduced or expanded during the next decade (Tech-63).

Trends in safety features (Tech-26), tires (Tech-28), advanced seat design (Tech-30), and other interior developments (Tech-29) suggest that aggressive change is occurring in practically all areas of the vehicle. Other areas of importance to technological planners include forecasts of trends in government regulation (Tech-12), international sourcing (Tech-86, Tech-87, and Tech-92), manufacturing (Tech-75 and Tech-81), and just-in-time inventory management (Tech-88 through Tech-91). The service industry is expected to be altered significantly as changes occur in the aftermarket (Tech-93) and both dealer and do-it-yourself service (Tech-94).

The current and future comparisons of North American and Japanese, and North American and German producers are evaluated (Tech-7 and Tech-8) and suggests that during the next ten years differences between the manufacturers will diminish based on various product quality factors.

The Delphi IV Technology forecast provides significant information for the automotive manufacturer and supplier as well as public utilities, and other service and financial organizations, labor, and government agencies that are in some way impacted by trends in the automotive industry. Effective strategic planning has never been more important if we are to properly address the complex, fast-changing, and challenging problems facing the automotive industry in the years ahead.

TECH-1. What is your estimate of retail fuel prices per gallon in the U.S. in 1990? 1995? 2000? (*In constant 1986 dollars;* that is, without adjusting for inflation.)

	Retail Price per Gallon					
	Median Response			Interquartile Range		
	1990	1995	2000	1990	1995	2000
Unleaded Gasoline	$1.20	$1.40	$1.75	$1.10/1.30	$1.25/1.50	$1.50/1.95
Diesel Fuel	1.20	1.40	1.65	1.10/1.25	1.30/1.50	1.50/1.80

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
1990 RETAIL FUEL PRICES

	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
	Forecast for 1990 In Current Dollars at the Time of the Survey			
Unleaded Gasoline	$2.50	$3.00	$1.60	$1.20
Diesel Fuel	2.40	3.00	1.60	1.20
	Forecast for 1990 Indexed to 1986 Consumer Price Index (CPI)			
Unleaded Gasoline	$3.77	$3.61	$1.76	$1.20
Diesel Fuel	3.62	3.61	1.76	1.20
CPI (1986=100.0)	217.4	272.4	298.4	*327.9

*June, 1986.

Selected Edited Comments

Conservation and OPEC's lack of strength will continue to hold retail prices low, as will U.S. consumer resistance to fuel taxes.

Due to tax exemption, methanol blending will help control price.

OPEC will not be able to get its act together again, so that will not be a factor; real supply and demand elasticity will occur, driving the price of petroleum up to the $25.00/ barrel range by 1995 and $30 to $35 by 2000. Fuel will also continue to carry a tax disproportionate to other consumer items.

Past ten years has indicated fuel prices are more sensitive to political pressures than to supply and demand.

This presumes that the oil cartel remains shattered. Pressures from debts on individual oil producing nations should be sufficient to reduce or eliminate any pursuit of a common interest among these nations.

Predicting the longevity of "cheap oil" is tough; assume a slight rebound in 1988 with continued upward, slow movement through '90s, and another "crisis" before 2000. Any tax to prop up crude pricing (unless western/worldwide) would hurt U.S. industries' global competitiveness.

Anybody's guess. U.S. is not in control of this.

As an excess commodity with downward price pressure from commercial users, diesel fuel will eventually regain its traditional price advantage over gasoline.

By 1990 OPEC should have pressured the high-cost producers to shut down exploration enough to allow another upward price spiral.

If fuel price stability can be achieved, prices will tend to reflect the true utility of motor fuel either ... via OPEC control or U.S. taxation. If stability is not achieved, expect continued fluctuations.

It is just a question of time until sources, foreign and domestic, get organized.

Sharp dislocations like those of the last decade will probably not be repeated, but the long-range supply/demand situation will drive costs gradually upward.

Situation is at best unstable. It is a function of world politics and willingness to invest in U.S. domestic exploration—also tax policies.

There is no technical reason diesel fuel should be more expensive than gasoline.

Assuming continued fuel economy pressures from government—even with lower gasoline prices.

Continued progress in fuel economy will slow or even reverse gradual increase in annual petroleum consumption, resulting in long-term stable or gradual small increases (at decreasing rate) in worldwide demand for petroleum.

U.S.'s shortsighted energy policy in late 80s will result in loss of domestic production and in later increases due to (1) short supply; (2) recognition of need to price to conserve.

We need to start considering fuel on consumption basis; smaller numbers are better, e.g., gals./100 miles. Further mpg reductions will make little contribution toward energy conservation and have very high incremental costs.

The surplus in addition to the CAFE curtailment of usage will hold the prices down. But price will go up due to limited resources.

Diesel fuel has to be the same or actually 10% higher when all the community realizes that we are selling and buying energy.

OPEC will not be a factor but growth pressures and renewed conservation based on recognition of the finite level of fossil fuel will raise price in early 2000s.

Discussion

Vehicle fuel prices are a key factor influencing practically all automotive product and marketing decisions. The fuel price question was asked first to establish a base of reference for most subsequent questions.

Unleaded gasoline prices are forecast at $1.20 per gallon in 1990, $1.40 in 1995, and $1.75 in the year 2000. As indicated by the interquartile ranges for these median responses, there is a good degree of consensus. The interquartile range table shows that 50 percent of the respondents predict a 1990 price in the range of $1.10 to $1.30 per gallon. Similarly, for the 1995 estimate, the interquartile range shows 50 percent of the respondents choosing an estimate between $1.25 and $1.50. The interquartile range for the year 2000 estimate is broader yet at $1.50–1.95 per gallon, but is not a bad consensus for a 14-year-away prediction.

When this question was asked in the 1983 Delphi III, the consensus was much tighter than shown here, where the narrowest interquartile range is 20 cents (between $1.10 and $1.30 for 1990) and the widest interquartile range is 45 cents for the year 2000 estimate. In the immediately previous Delphi, the widest interquartile range was 20 cents and the narrowest was only 5 cents. The broadening of the interquartile ranges was expected in view of the experience of the last two or three years with OPEC losing partial control of fuel prices which have, therefore, varied rapidly and unpredictably in parallel with day-to-day international politics.

The median forecast for diesel fuel in 1990 is $1.20 per gallon, the same as for unleaded gasoline; $1.40 in 1995, again identical with the gasoline forecast; and $1.65 in the year 2000, or 10 cents less than the gasoline forecast. The interquartile ranges are slightly tighter for diesel fuel than for unleaded gasoline.

Discussion of Panelists' Comments

Selected edited comments from the panelists are shown following the retail price-per-gallon tables. A single comment can provide an insight of high value to a particular individual, firm, or organization associated with the industry. However, 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. Of course, one point in collecting and displaying comments is that, perhaps, one or more of them could lead to contrary action.

Comparison of Vehicle Manufacturers and Supplier Panelists

Panels include some respondents employed with motor vehicle manufacturers and others working for their suppliers of components, parts, and materials. It is common within the industry and convenient here to refer simply to "manufacturers" and "suppliers."

For competitive reasons the manufacturers seek to maintain secrecy regarding their plans, and it might be presumed that their representatives would therefore know more than others about the future direction of the automotive industry. On the other hand, vehicle manufacturers source half or more of each finished product from suppliers and, ideally, they should establish a close working relationship, so that there are few real secrets between them. However, the size of the industry and complexity of the information system works against optimum information transfer. Therefore, our analysis includes a comparison of answers from manufacturer and supplier respondents to determine if there are significant differences.

Regarding fuel prices, both groups gave very close median forecasts for both unleaded gasoline and diesel fuel in 1990 and 1995. The forecasts for diesel fuel were identical and the unleaded varied no more than five cents. For the year 2000, the vehicle manufacturer respondents forecast $1.60 for unleaded and $1.55 for diesel; the supplier panelists predicted $1.75 for unleaded gasoline and $1.70 for diesel fuel.

Comparison of Replies to MKT-4 and MAT-1

The three groups of panelists (Technology, Marketing, and Materials) contacted for this study were asked questions that focused on their area of expertise. A few questions, however, were considered common to two or more panels. This question regarding fuel prices was considered so basic that it was asked of all the panelists.

The Marketing panelists' median forecast for 1990 fuel prices were identical with the 1995 forecasts and were only five cents lower than Technology. For the year 2000, Marketing was fifteen cents lower for unleaded gasoline and only five cents lower for diesel.

The Materials panelists display a pattern of being consistently higher than the Technology and Marketing panelists in their forecasts for the years 1995 and 2000. Since the Materials panel consists of selected panelists from the fuels and lubricants industry, their forecasts should be given serious consideration.

	Technology Panel			Marketing Panel			Materials Panel		
Fuel	1990	1995	2000	1990	1995	2000	1990	1995	2000
Unleaded	$1.20	$1.40	$1.75	$1.20	$1.35	$1.60	$1.25	$1.70	$2.00
Diesel	1.20	1.40	1.65	1.20	1.35	1.60	1.20	1.70	2.00

Trend from Previous Delphi Surveys

Figure T-1 shows median responses from four Delphi surveys for 1990 fuel prices. In 1979, at the time of Delphi I, respondents forecast that gasoline would be $2.50 per gallon. In the 1981 Delphi II survey, the median forecast was $3.00 per gallon for unleaded gasoline. In 1983, the prediction dropped to $1.60 per gallon and in Delphi IV, our latest survey, has continued its decline to $1.20. Each of these figures is in current dollars (at the time it was forecast) and does not reflect an allowance for inflation—which has, of course, occurred since the earlier survey dates.

When earlier data are adjusted to 1986 prices, the 1990 forecasts for gasoline were $3.77 per gallon in 1979, $3.61 in 1981, and $1.76 in 1983, as compared to the $1.20 per gallon median response in the 1986 Delphi IV survey.

The forecast trend for diesel fuel is almost identical to that of gasoline. These trends are also shown graphically in Figure T-1.

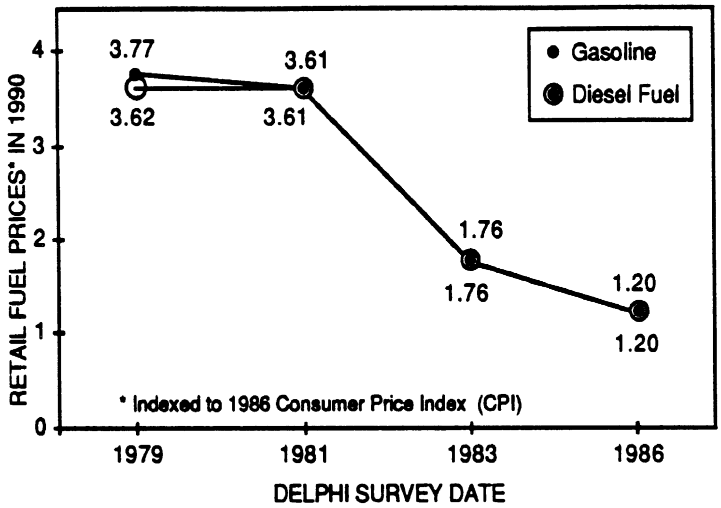

FIGURE T-1. Retail Fuel Prices* in 1990
Median Forecasts from Previous Delphi Surveys

Strategic Considerations

The continuing decline in 1990 fuel price forecast to a level less than half of predictions made in earlier surveys is not an indictment of our earlier panelists (many of whom are panelists in Delphi IV), but a warning that even experts cannot be certain of a future which is, as in this case, determined by politics rather than free markets. Lower recent forecasts reflect a return to "freer markets" for fuel pricing in the U.S., but the occurrence and timing of domestic political changes that enabled that return could not have been judiciously forecast.

It may appear the panelists are predicting no recurrence of government interference in energy markets before 2000—a forecast that would seem highly unlikely with four presidential elections in the period and continued Middle East instability. Fourteen years is a long time to expect relatively stable supplies and prices for energy, and our panelists are, of course, keenly aware of the fact. But they lack a method to predict the timing or extent of a political or military impact.

TECH-2. Assuming that the maximum CAFE fuel economy level of 27.5 miles per gallon (EPA combined city/highway cycle) is maintained, what is your fuel economy forecast for U.S.-produced (U.S.-owned companies) passenger cars in the model years 1990 and 1995?

	EPA Combined Cycle Fuel Economy (mpg)			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
U.S. Passenger Cars	28 mpg	30 mpg	27.5/28.5 mpg	28.0/31.0 mpg

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
1990 FUEL ECONOMY (MPG)
CARS PRODUCED IN U.S. BY U.S.-OWNED COMPANIES

	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
U.S. Passenger Cars	30 mpg*	35 mpg	30 mpg	28 mpg

*Estimate based on related questions.

Selected Edited Comments

At likely low future fuel prices, U.S. cars are already more fuel efficient than consumers desire. Fuel cost, at 2% of total life-cycle cost, will remain below historical levels well into the 1990s. Given continued consumer demand for performance, comfort, and safety (extra weight) and continued, albeit, more rational regulatory pressure to reduce emissions, advances in engine technology will not significantly focus on fuel economy. Advances that do occur will compensate for weight increases and more stringent emissions regulations.

CAFE no longer necessary. Fuel price/availability situation and market forces will control adequately.

I believe the mix of fuel efficient and big cars will even out at the level the law requires, particularly so for the broad product line companies, i.e., GM and Ford. Chrysler and AMC may better the average simply because of their lack of *big* cars, but that factor could be moderated by "performance" vehicles that tend to be less fuel efficient.

Market shift to bigger cars will offset tech gains.

The industry has made some great steps forward in respect to fuel economy. I suspect new improvements in fuel economy will be much more difficult, unless some totally new technology is developed.

With the current trend in fuel prices the demand for larger cars will increase.

Aerodynamics, electronics, and combustion chamber improvements will continue to improve vehicle efficiency.

CAFE could be driven significantly higher if fuel prices drives market demand in that direction. However, people love performance and will pay a lot to get it.

Customer demand does not support higher levels.

CAFE is far stronger driving force for fuel efficiency than customer demand.

Assume the trend of buying big cars will continue for another two to three years.

Results are highly dependent on fuel price stability, which impacts model mix and sales volume of performance engines.

Rising gasoline prices will be the main driver to shift to small cars and improve CAFE post-1990. High tech will be employed to improve performance while maintaining economy.

Technology improvements will be used up in performance and car size to please the consumer, who will adjust to slow escalation of fuel cost.

Continued material substitutions, e.g., plastics, will increase mpg ratings.

Even though CAFE is assumed to remain 27.5 mph, technological advances in vehicle construction (material replacement programs), engine and transmission innovations, and consumer awareness will continue to push Detroit to make better products.

Fuel economy will not improve until a fuel shortage occurs.

I do not believe the U.S. OEMs will attempt to improve economy beyond that mandated by law unless outside influences, such as another fuel availability crisis or markedly higher prices, cause the customer to demand better economy.

Discussion

Panelists forecast that by 1990 the average fuel economy for U.S.-produced passenger cars will be 28 mpg as measured by the EPA combined city/highway cycle. This increase is expected even if the CAFE fuel economy requirement remains at 27.5 mpg. By 1995, the average is forecast to be 30 mpg. As shown in the second part of the table, interquartile ranges are reasonably close and show good consensus on the median forecast.

Discussion of Panelists' Comments

Panelists' comments touch on a number of major issues, including the conflict between customer demand and government CAFE requirements. Some of the comments express doubt that 27.5 mpg will be achieved or maintained. In evaluating such comments the reader should keep in mind that they reflect the opinions of the 25% of the respondents who forecast fuel economy in 1990 at 27.5 mpg or less, as shown in the lower end of the interquartile range. Comments doubting the attainment of 28 mpg should not be overweighted in view of the fact that 75% of the respondents forecast an mpg of 27.5 or higher.

Comparison of Vehicle Manufacturer and Supplier Panelists

Vehicle manufacturer and supplier respondents gave identical median forecasts at 28 mpg in 1990 and 30 mpg in 1995.

Trend From Previous Delphi Surveys

In the 1979 survey, respondents forecast U.S.-produced passenger car average fuel economy at 30 mpg in 1990. In the 1981 survey the forecast for 1990 had increased to 35 mpg. But, in the 1983 Delphi III survey, the prediction dropped back to 30 mpg and has declined in this fourth survey to 28 mpg. These changes are as would be expected from the decline both in the level and trend of fuel prices in recent years. After all, when adjusted for inflation, retail fuel prices at the pump are back to pre-World War II levels.

Strategic Considerations

The most dramatic change in American cars in recent years has been in fuel efficiency. Domestic U.S. manufacturers have improved the average fuel economy of their cars from approximately 12 mpg in 1974 to 26–27 mpg currently. But economy improvements are approaching the point of rapidly diminishing returns.

There is a limit to the dollar value of fuel economy, particularly if the effort to achieve CAFE produces a much more costly car or an impractically small vehicle. Some motorcycles get 125 mpg, but lack utility for a family of four with a dog and a boat trailer.

The objective here is to put fuel economy into perspective; it is important, but so are other vehicle characteristics. The vehicle's designers and its buyers must consider an array of consumer value factors, including package size, performance, comfort, durability, and safety. The key word in evaluating fuel economy, or any other vehicle characteristic, is "optimum": enough, but not too much. Manufacturers must strive to offer products that meet consumers' trade-off analyses. This is by no measure a trivial task.

		A $1.00/Gal.		B $1.50/Gal.		C $2.00/Gal.	
MPG	GAL'S	COST	GAIN	COST	GAIN	COST	GAIN
10	1000	$1000		$1500		$2000	
20	500	500	$500	750	$750	1000	$1000
30	333	333	167	500	250	666	334
40	250	250	83	375	125	500	166
50	200	200	50	300	25	400	100

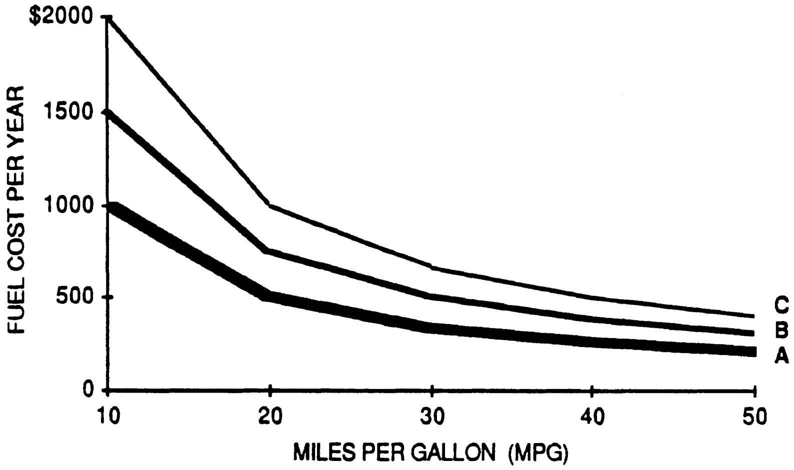

FIGURE T-2. The Declining Value of Incremental Gains in Fuel Economy

Figure T-2 shows the relationship between car efficiency and annual fuel costs. For example, at $1.00 per gallon, a gain or annual savings of $83 is achieved by moving from a 30 mpg car to one that gets 40 mpg. But this $83 change can also be evaluated from the other direction.

If you own a subcompact, two-adults plus two-small-children car that achieves 40 mpg, would it be worth an extra $83 per year in fuel costs to drive a 30 mpg model that has room inside for five adults plus their luggage? This is the kind of question that Americans—including those responsible for designing American (and imported) cars—ask themselves. Recently, car buyers in the U.S. have been answering by buying larger cars. Particularly since the price of gasoline fell below $1.00 per gallon.

However, the design and purchase answers cannot be based solely on financial and comfort considerations or in permanent free-market energy. Consequently, economics may not be sustainable in the future. Vehicle buyers and designers must keep in mind the question of fuel availability as well as price.

TECH-3. Of the passenger car fuel improvement scheduled for 1990 and 1995, what percentage of the improvement will come from the following factors?

	Percent of Total MPG Improvement			
	Median Response		Interquartile Range	
Improvement	1990	1995	1990	1995
Improved drivetrain efficiency incl. transmission improvements	23%	22%	18/29%	16/27%
Improved engine efficiency	23	22	18/33	16/27
Weight (but not size) reduction through increased use of lightweight materials	18	20	12/24	15/22
Improved aerodynamics	12	11	9/18	9/13
Downsizing	6	5	6/12	3/11
Reduced tire rolling resistance	6	5	6/12	5/11
Reduced performance (lower power/weight ratio)	0	0	0/6	0/5
Others†	12	15	6/18	5/17
TOTAL	100%	100%		
†Also mentioned in "Other" category:				
Improved accessory drives	10	10	6/20	8/20
Alternate fuels or additives	10	15	5/15	10/25
Alternate powertrains**	0,3	15,25		
Change in vehicle mix	20*	10,20**		
CVT*	10	10		
Increased use of manual transmission*	5	5		
Improved tires*	5	5		
Electronic powertrain controls*	10	15		
Obsoleting old engines*	—	80		

*Indicates a single response.
**Indicates two responses.

MEDIAN FORECASTS FROM THREE DELPHI SURVEYS
1990 FUEL ECONOMY IMPROVEMENT FACTORS

	Forecast for 1990 at the Time of the Survey		
Improvement	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Aerodynamics	10%	12%	12%
Tire Resistance	5	6	6
Engine Efficiency	15	23	23
Improved Drivetrain Efficiency	10	23	22
Downsizing	30	14	6
Weight	20	17	18
Others	10	5	13
TOTAL	100%	100%	100%

Selected Edited Comments

Aerodynamic improvements are not that significant at U.S. speeds and will be well underway by 1990, with diminishing returns thereafter. Bulk of improvements will come from integration of engine/drivetrain electronics rather than component improvements. Since underlying market trends will require more performance and more weight for consumer comfort and options, use of more lightweight materials will grow in importance, perhaps escalate in the mid-1990s with space-frame body designs becoming more common.

Forthcoming materials will improve weight in powertrain and body. CVT transmissions electronically coupled to engine controls promise enormous improvements; however, materials must be refined to implement them.

Performance will be increased—a negative factor.

All factors considered, while many improvements will be realized, the size and performance will be maximized while meeting the CAFE requirements.

CVT transmissions and integrated powertrain controls will be biggest contributors.

I expect car performance and size to increase with constant fuel economy, assuming no change in laws.

Lightweight transmission systems, more use of plastics, increased engine efficiency through design and materials application, more compact power plants.

This analysis is on an average model and is independent of market mix. Higher gas prices in 1995 will minimize the performance improvements.

Assuming U.S. owned: Then no improvement in 1990-1995 overall. Car line improvement as shown in big cars will be offset by loss of low-end product with corresponding high mpg ratings.

New drivetrain technologies will influence this area. Competition will dictate degree of involvement (4x4 cars).

Automotive engineers are maturing, which is leading into designing for engineering materials. As structural adhesives are developed, future cars will be a hybrid of different materials. This will cause an extensive reduction of car weight without reducing the principal size of the vehicle.

Understanding and application of a true system approach will yield the greatest benefit.

Discussion

Improvements in fuel economy can be achieved by several methods. One of the easiest is to reduce the ratio of power to weight, e.g., maintain the weight of a vehicle while decreasing the size of its engine or reducing its axle ratio. But there are limitations on these actions. For example, a lawn mower engine would not be adequate to power a six-passenger car. And long before this limit is reached there arise problems of inadequate performance. The vehicle is unable to climb hills, is unsafe when passing, etc.

Another relatively easy method (cost of redesign and tooling aside) of improving fuel economy is to reduce vehicle size. There are obvious limits here because if the vehicle becomes too small it is not practical for most consumers.

The more challenging techniques to improve fuel economy are through improved aerodynamics, reduced tire rolling resistance, improved engine efficiency, improved drivetrain and transmission efficiency, and weight (but not size) reduction through the increased use of lightweight materials and improved design efficiency.

This question provides forecasts of methods that will be used to improve fuel economy through the next eight years. Reflecting long-term trends, discussed in more detail below, no further impact is expected from reduced performance, that is, from lowering the power/weight ratio. And further downsizing is expected to contribute only 5% or 6% of total mpg improvement by 1995. The major contributors, at over 20% each, are improved engine efficiency and drivetrain efficiency. Further weight reduction is also expected to contribute nearly 20%. Improved aerodynamics and reduced tire rolling resistance are expected to contribute significantly at 11-12% and 5-6%, respectively.

These percentages refer to the mix of improvement methods. For example, improved engine efficiency is shown accounting for 22% of the total mpg improvement in 1995. This is a forecast that engines will account for 2.2 percentage points if the overall vehicle economy improvement is 10%.

The interquartile ranges are fairly broad but not bad for this particular forecast. The important information they convey is that there appear to be no extreme differences of opinion.

Discussion of Panelists' Comments

Comments include a variety of viewpoints, several of which either directly or indirectly reflect the difficulty of forecasting in the face of unpredictable non-market factors.

Comparison of Vehicle Manufacturer and Supplier Panelists

There is no significant difference between the forecasts of the vehicle manufacturers and supplier panelists.

Trend from Previous Delphi Surveys

Delphi IV results, when compared to those of Delphi II and Delphi III, show the changing pattern of efficiency efforts (see median table on page 13). Downsizing, which was the leading forecast improvement factor at 30% for 1990 at the time of the Delphi II survey, has declined to 6% in the 1986 survey. This does not mean that the earlier survey was wrong, but only that most of the downsizing has now taken place. Interestingly, the improvement expected from the first four factors: aerodynamics, reduced tire rolling resistance, engine efficiency, and drivetrain efficiency, were the same for our 1986 survey as they were three years ago at the time of Delphi III. Efforts to reduce weight will continue to be a significant effort, with 18% of the 1990 improvement expected from weight reduction at the time of this current survey.

Strategic Considerations

The primary message to be gathered from these data is that the automotive industry has made most of the straightforward changes needed/necessary to improve economy and must now concentrate on the harder path of improved engineering and design in several areas. Note particularly the expected growth in efficiency contribution from the drivetrain and engine.

Changing emphasis among economy improvement factors is in line with other evidence throughout the study that the move to smaller, lighter passenger cars has slowed considerably. It is obvious that technology is expected to play a far greater role than the original fuel economy improvement technique of downsizing. This trend is strongly reinforced by a market that is demanding a wide array of often conflicting product virtues including people and luggage capacity and better performance.

New materials/downsizing has resurged from a lower rating in Delphi III. This suggests important new materials/manufacturing developments may be on the horizon. The reduced-performance option has reached its limit.

TECH–4. What will be the average weight in pounds (dry curb weight), wheelbase, overall length, width, and height in inches for U.S.-produced passenger cars in the following size classes in 1995?

1995 Model Year EPA Class Size*	Dry Curb Weight	Wheel-base	Overall Length	Width	Height
			Median Response		
Mini/Sub Compact	1900 lbs	94 in	160 in	64 in	51 in
Compact	2250	100	175	67	52
Midsize/Large	2900	105	190	70	54
			Interquartile Range		
Mini/Sub Compact	1800/2000	90/95	155/165	63/65	50/53
Compact	2200/2450	98/100	170/179	65/67	52/53
Midsize/Large	2700/3000	104/108	185/196	68/72	53/55

*This is the first Delphi survey in which we are using EPA classification rather than a constantly changing industry classification. See page 18 for a cross reference of passenger car models by EPA vs. industry classification.

Selected Edited Comments

Most mini/sub compact cars produced in the U.S. will be Japanese designs by 1995. Use of EPA cross size definitions includes some large cars with small interiors in the compact segment.

Weight will continue to decline—size will remain the same.

Same as today. Cars will not get smaller.

Discussion

Respondents forecast car-size dimensions for mini/subcompact, compact, and midsize/large cars. We were particularly interested in ascertaining if there is any movement back to the large cars of the past. No such trend is indicated. Even the midsize/large car's overall length at 190 inches, or less than 16 feet, is significantly below past averages for this size vehicle. At one time, 18 feet was a common length for large cars.

Discussion of Panelists' Comments

The comment that cars will not get smaller but stay the same as today is not in accord with the numerical forecasts which indicate continued declines in overall length.

Comparison of Vehicle Manufacturer and Supplier Panelists

Supplier and manufacturer weight forecasts were very close, within 5% or less of each other; dimensional predictions were either identical or varied no more than 2%.

Strategic Considerations

There will still be a few large passenger cars but designers of highways, parking lots, and other physical facilities for their accommodation should be sure that plans reflect the reality of vehicles substantially smaller on the average than those produced in the past.

1986
EPA CLASSIFICATION

		MINICOMPACT	SUBCOMPACT	COMPACT	MID SIZE	LARGE	TWO SEATER
DOMESTIC	Subcompact		Chevette, T1000, Sentra, Turismo, Charger	Escort, Lynx, Horizon Omni, Encore, Alliance, Golf			Fiero, EXP
DOMESTIC	Compact		Camaro, Firebird, Mustang, Capri, Laser, Daytona, Accord	Cavalier, T2000, Firenza, Skyhawk, Tempo, Topaz, Grand Am, Calais, Somerset, Skylark	Le Baron, Reliant, Aries		
DOMESTIC	Intermediate			Thunderbird, Cougar, Eagle	Celebrity, 6000, Bonneville, Ciera, Supreme, Century, LTD, Marquis, Caravelle, New Yorker, 600, Monte Carlo, Grand Prix, Regal, GTS, Lancer		
DOMESTIC	Full Size				Diplomat, Grand Fury, Fifth Avenue	Chevrolet, Pontiac, 88, Le Sabre, Crown Victoria, Grand Marquis	
DOMESTIC	Luxury			Cimarron	Toronado, Riviera, Seville, Eldorado, Continental, Mark VII	98, Electra, Deville, Town Car	Corvette
IMPORT		GTV, Sprint, RX-7, 911, Cabriolet, Forsa	Coupe, Quattro, 4000S, Spectrum Civic, Prelude, Accord, I-Mark, Impulse, XJ- 8, X3-6, 190, Cordia, Mirage, Starion, Tredia, Pulsar NX, Sentra, 200 SX, 300 ZX 2+2, Colt, Conquest, Fuego, Corniche II, Subaru XT, Forsa V, Celica, Supra, Corolla Sport, Tercel, Scirocco	5-Series, Nova, 323, 626, 300E, 560 Sec, XR471, Galant, Maxima, Stanza, 505, Camarque, 900, Subaru Sedan 3-door, Camry, Corolla, Cressida, GTI, Jetta, Jetta GLI, Quantum, 240DL/GL	5000 CS, 500 S, 420 SRL, 560 SRL, Silverspur, 740/760	9000	Spider, X 1/9, Civic, Coupe, 560 SI, 300ZX, XT-DI, 11R2

TECH-5. What will be the average wheelbase, overall length, width, and height for U.S.-produced light trucks in the following gross vehicle weight (GVW) classes in 1995?

1995 Model Year GVW Class (0-10,000 lbs.)	Wheel-base	Overall Length	Width	Height
	Median Response *(In Inches)*			
Mini Van	108	170	69	66
Vans	118	185	75	75
Compact Pickup	108	175	65	62
Conventional Pickup	120	190	73	70
	Interquartile Range *(In Inches)*			
Mini Van	105/111	168/175	65/70	65/73
Vans	115/120	180/195	72/79	75/79
Compact Pickup	103/113	170/180	62/66	61/65
Conventional Pickup	115/125	189/204	69/76	68/70

Selected Edited Comments

I don't see much change in light-truck sizes or weights except that FWD will come to dominate the minivan market.

New size small van like Chrysler's will come from GM and Ford.

New smaller pickups will be derived from FWD passenger cars.

GVW ratings will basically stay the same with longer wheelbase options available for special needs.

Discussion

Compared to existing light trucks in the 0-10,000 lb. GVW range, our respondents forecast that light trucks will be slightly smaller than present models.

Discussion of Panelists' Comments

There is little expectation for significant changes in light truck size.

Comparison of Vehicle Manufacturer and Supplier Panelists

Manufacturer and supplier predictions on weight and dimensions were close with the exception of conventional pickup width where the manufacturers' median forecast was 76 inches compared to 69 inches by suppliers. The 73-inch forecast shown here is, of course, the weighted average of those two figures.

Strategic Considerations

See "Strategic Considerations" discussion under Tech-4. It is also important to recognize that the sizing of many of the vehicles is defined by the load they are expected to carry. A 4'x8' sheet of plywood will probably remain a 4'x8' sheet.

TECH–6. Forecast the material content, in pounds, and the total curb weight (dry, unloaded) for the average U.S.-produced passenger car for model years 1990 and 1995.

Materials	Est. 1985	Median Response 1990	Median Response 1995	Interquartile Range 1990	Interquartile Range 1995
STEEL					
Low Carbon Steel		1135 lbs.	925 lbs.	1050/1200 lbs.	900/1020 lbs.
HSLA Steel		250	300	250/262	275/300
Stainless Steel		25	35	25/35	30/50
Other Steels		115	100	110/125	100/110
TOTAL	1680	1525	1360	1485/1555	1270/1390
Cast Iron	430	375	300	350/400	300/350
ALUMINUM Castings		120	146	110/130	120/160
Wrought Aluminum		35	40	30/40	35/50
TOTAL	135	155	186	150/165	185/215
PLASTICS					
Unreinforced (no fiber content)		100	125	70/135	75/145
Reinforced (<40% fiber content)		100	100	75/100	90/125
Structural Reinforced Composites (>40% fiber)		43	70	10/80	40/100
TOTAL	190	243	295	228/280	220/345
Copper	25	22	19	20/25	15/20
ZINC (exclude coatings)	13	12	10	10/13	10/11
Zinc Coatings	12	12	12	11/12	10/12
Magnesium	1	2	3	1/3	1/5
Glass	85	85	80	80/85	75/85
Ceramics	1	2	5	2/3	3/8
Powdered metals	25	25	30	25/30	25/35
RUBBER					
Tires (include spare)		100	90	90/100	85/95
All Other Rubber		30	30	25/35	25/30
TOTAL	135	130	120	130/135	115/125
Total All Other (includes insulation, cloth, carpets, foam, fluids, etc.)	140	140	149	120/140	110/140
TOTAL VEHICLE	2872	2728	2569		

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
POUNDS OF MATERIALS IN 1990 MODEL
U.S.-PRODUCED PASSENGER CARS

	Forecast for 1990 at the Time of the Survey			
Materials	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Steel	1400 lbs	1300 lbs	1400 lbs	1525 lbs
Aluminum	200	200	137	155
Plastics	300	300	225	243
Cast Iron	250	250	270	375
Other	365	200	387	430
TOTAL	2515 lbs	2250 lbs	2419 lbs	2728 lbs

Selected Edited Comments

The auto industry is based on steel. The capital equipment and existing plants and processes on hand that are already in excess capacity will delay the change to plastic and aluminum.

Expect increase in paint materials and other corrosion resistant coatings.

Structural reinforced composites in springs only.

Old designs will be phased out, driving carbon steel and cast iron usage down. Look for more plastic panels and some structural components.

The unknown is the amount of ceramic usage in the power plant.

There is enough experimental evidence that structural reinforced composites will be capable of handling energy management. Therefore, I expect a significant increase in structural reinforced composites especially in class B surface members and components. This is also dependent on machinery development for laying glass fibers.

Copper content will increase, because of more electrical wiring.

Discussion

The weight of the average U.S.-produced passenger car is expected to continue to decline from an estimated 2,872 pounds in 1985 to 2,728 pounds in 1990 and 2,569 pounds in 1995.

As recently as 1976, the average U.S.-produced passenger car contained over 2,000 pounds of steel. As cars have been downsized and downweighted, this usage has dropped and is forecast to decline to 1,525 pounds in 1990 and 1,360 pounds in 1995. Almost all of this decline is taking place in low carbon steel as HSLA (high strength, low alloy) steel is expected to increase to 300 pounds per vehicle in 1995, while stainless steel increases to 35 pounds.

Aluminum usage is predicted to increase from an estimated 135 pounds in 1985 to 155 pounds in 1990 and 186 pounds in 1995. However, as will be seen in the trend analysis, this growth, if achieved, will not equal earlier forecasts.

Total usage of plastics is predicted to increase to 243 in 1990 and 295 in 1995. As with aluminum, however, these forecasts are below those made in previous Delphis.

Cast iron usage is expected to decline, but not to the previous low levels foreseen.

Copper usage is expected to continue to decline, while zinc just about holds its own as do powdered metals. The newcomers, magnesium and ceramics, show a substantial percentage growth but not large absolute usage.

Considering the detail and depth of this materials analysis, we believe the interquartile ranges are good and for selected items, such as HSLA steel, stainless steel, cast iron, and aluminum, the interquartile ranges are unusually tight.

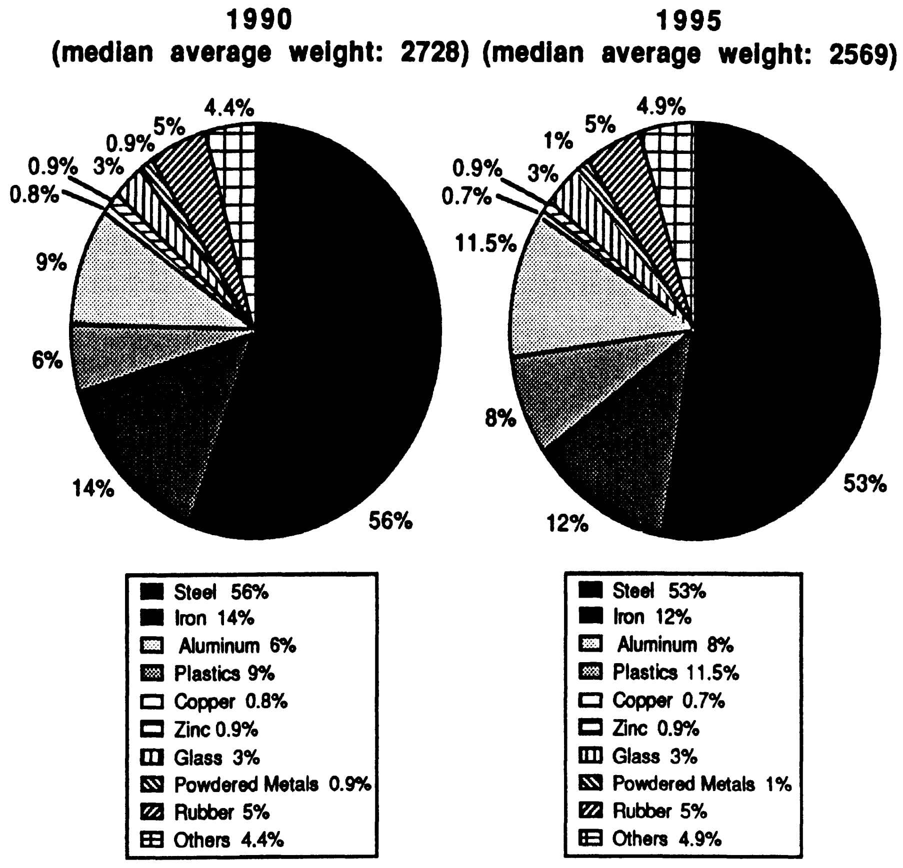

FIGURE T-3. U.S.-Produced Passenger Cars: Projected Use of Materials (based on material weight)

Discussion of Panelists' Comments

The first comment points out that the existing infrastructure discourages rapid abandonment of steel.

Comparison of Vehicle Manufacturer and Supplier Panelists

The two groups of panelists were remarkably close on all of their detailed materials forecasts. Many predictions were identical. There were no significant differences.

Comparison of Replies to MAT-5

The forecasts by the Technology panelists and the Materials panelists for the material content of the average US passenger are remarkably similar. Those forecasts that varied more than 10% are as follows.

	Technology Panel	Materials Panel
HSLA Steel: 1995	250 lbs	310 lbs
Stainless Steel: 1990	25	10
Stainless Steel: 1995	35	20
Plastics		
Reinforced <40% Fiber: 1990	100	80
Reinforced <40% Fiber: 1995	100	120
Structural Reinforced: 1990	43	20
TOTAL VEHICLE: 1995	2569 lbs	2600 lbs

Trend from Previous Delphi Surveys

When comparing forecasts for 1990, a decreasing rate (but not a reversal) of weight reduction is apparent over the four Delphi surveys. The total weight of the average vehicle as forecast for 1990 declined from 2,515 pounds in the Delphi I survey, to 2,250 pounds in Delphi II, but reversed its direction to 2,419 pounds in Delphi III, and it now has increased to 2,728 pounds in Delphi IV. These changes are largely attributable to changing fuel price expectations.

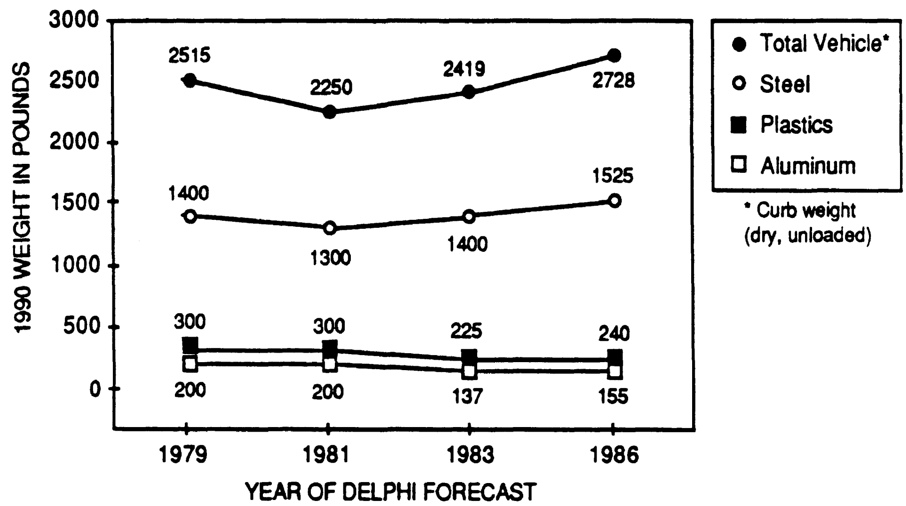

FIGURE T-4. Weight of Average U.S.-Produced Passenger Car

Strategic Considerations

What is most remarkable about these materials forecasts is their indication of a continual shrinkage in materials usage. Recent motor fuel prices, adjusted for inflation, are at pre-World War II levels and below what they were in the late 1960s during the great popularity of very large American-made passenger cars. This would suggest that a trend to larger vehicles could develop.

However, a major reason why this trend is not taking place is the uncertainty of long-term fuel availability. As discussed earlier, under the "Strategic Considerations" accompanying question Tech-2, manufacturers and consumers must consider not only the price of the fuel but the possibility that supplies can be arbitrarily disrupted at any given moment. Additionally, government controls such as CAFE standards are a barrier to larger cars.

However, and consistent with other related issues, the expected rate of vehicle weight reduction is slowing markedly from that forecast in earlier Delphis. Even though there is growing moderation in expectations for shifts in automotive materials for the future, there is strong support for lighter weight materials as evidenced by the forecast significant percentage growth in plastics and aluminum from Delphi III to Delphi IV.

In our judgment, materials and their processing will be one of the most exciting and volatile areas of technology in the coming decade. Developments must be watched closely. This is particularly difficult because of the diverse technologies and large number of potential sources of technology. Furthermore, many of the more conventional technologies are being reevaluated and may yield improvements well beyond the current "state of the art." Steel, for example, is experiencing renewed interest because of consideration of a far more systematic approach in the total process of converting the raw material to the finished product.

A true systems approach in automotive materials may emerge in which a hybrid set of materials are developed which use the best of metal and polymer technology. The seeds of this are beginning to germinate in some of the more creative automotive and material companies. One of the great uncertainties in the material competition is the relative infancy of "plastics" technology. Who really can forecast with great precision developments in the materials and their processing ten to twenty years from now?

TECH-7. Check your estimate of how a domestically produced (U.S.-owned companies) passenger car compares today and will compare in 1990 and 1995 with imported *Japanese* vehicles.

	U.S. Passenger Car Versus Japanese Vehicle		
	Higher Quality	About Same	Lower Quality
Fit and Finish			
Today	1%	14%	85%
1990	5	73	22
1995	19	74	7
Basic Structural Integrity of Body and Chassis			
Today	42	45	13
1990	39	58	3
1995	41	56	3
Engine and Drivetrain Integrity and Durability			
Today	22	29	49
1990	20	63	17
1995	26	68	6
Maintenance Requirements			
Today	22	43	35
1990	19	70	11
1995	24	73	3
Corrosion Resistance			
Today	61	32	7
1990	47	51	2
1995	42	57	1
Ride and Comfort			
Today	58	34	8
1990	52	46	2
1995	46	52	2
Styling			
Today	36	40	24
1990	29	65	6
1995	36	60	4
Handling			
Today	21	46	33
1990	17	69	14
1995	21	72	7

	U.S. Passenger Car Versus Japanese Vehicle		
	Higher Quality	About Same	Lower Quality
Safety			
Today	80%	20%	0
1990	70	29	1
1995	55	45	0
Total Car Reliability			
Today	4	21	75
1990	8	67	25
1995	19	72	9
Fuel Economy			
Today	1	15	84
1990	1	54	45
1995	7	73	20
Driveability			
Today	19	44	37
1990	24	68	8
1995	28	70	2

Selected Edited Comments

By 1995 it will be more difficult to differentiate due to increased imported parts content.

Comparison of such qualities as ride, comfort, handling, and fuel economy can only be made between similar types of vehicles.

Of the few Japanese cars I have driven, and/or inspected, I can't say I have ever been overly impressed. The common opinion that Japanese cars are so much better than U.S. is, in my opinion, a myth.

The Japanese are making significant technological progress which, if not matched by the U.S. manufacturers, will render U.S. cars less competitive in the future.

These answers are subjective. It is very difficult to rate and compare the products over the total product line.

Engine/drivetrain durability: Historically a U.S. strong point, but Japanese strides (e.g., better surface finishing from advanced machining) and U.S. fumbles on new introductions (e.g., port injection, FWD, automatic transmissions) give them temporary advantage.

Many of above items like "comfort, handling and driveability" are subjective and depend on individual consumer needs.

I feel U.S. auto companies will meet technical challenges of Japanese auto companies by 1990.

On average, Japanese imports have higher fuel economy now. However, as they continue to place more and more emphasis on foreign markets, current trend of larger

Japanese export vehicle size and bigger engines, *plus* domestic drive to smaller cars and engines will make U.S. and Japanese vehicles similar in economy by 1990.

U.S. will lead Japan in adoption of plastics and other corrosion-resistant technologies.

We have come a long way—we still have a long way to go for the] total U.S. industry. We can and will equal the Japanese—we will not exceed them in very many categories.

Japanese are still learning about vehicles for U.S. consumer in terms of environment and usage.

Discussion

We believe that quality should be defined broadly to include not only fit and finish and other highly visible characteristics of light duty vehicles but, in addition, other quality factors such as safety, corrosion resistance, handling, etc.

In question Tech-7, American cars are compared to Japanese and judged to be either of higher quality, about the same, or of lower quality on twelve separate quality factors. The question asks for quality comparisons today, and forecasts for the years 1990 and 1995.

Today, American cars are rated higher than the Japanese on corrosion resistance, ride and comfort, and safety. Japanese cars are rated higher than American cars, today, on fit and finish, engine and drivetrain integrity and durability, maintenance requirements, handling, total car reliability, fuel economy, and driveability.

The main finding of the forecasts is that by 1995 the cars manufactured in America and Japan are expected to converge in their quality ratings, with the result that cars from these two sources will rate about the same. The one noticeable exception to this pattern is that in the safety area, U.S. vehicles are expected to maintain a significant lead.

Generally the results are similar to the findings of Delphi III.

Discussion of Panelists' Comments

Several of the comments touch on the fact that today's fuel economy rating advantage of Japanese cars reflects the smaller size of these vehicles. Independent studies, based on engineering criteria, show that when matched for size, weight, and volume, American cars closely match Japanese cars on fuel economy. The Delphi survey, however, is measuring a perception that is important and should be addressed by American manufacturers to be assured that consumers are aware of the facts.

Comparison of Vehicle Manufacturer and Supplier Panelists

The two groups of panelists provided forecasts that were of the same order of magnitude, but there is a clear pattern of consistently higher rating of U.S. vehicles among manufacturers than among suppliers.

Strategic Considerations

It might be thought that the forecasts for 1995 are wishful thinking on the part of our panelists, most of whom represent the U.S. automotive industry. However, Japanese automotive experts agree with these trends. One of their great concerns is that the U.S. industry has the capability of meeting any customer demand. They believe the U.S. automotive industry can, in time, match the Japanese on any and all quality factors.

If, as forecast, U.S. and Japanese cars reach parity on quality, these items will become less significant in product differentiation. Other factors, such as technology, lead time, styling, price, and selling and sourcing factors, will increase in competitive importance.

It is clear that today's customer is more quality conscious than in the recent past. Increasingly, world-class quality, however it is measured, is likely to become a basic demand. All vehicles will have to meet these requirements. Quality parity is not an option for the successful manufacturer or supplier.

Some quality virtues are reasonably objective while others are highly subjective, e.g., styling, handling, etc. The customer perception of the product will be extremely important and reinforce the view that we are, indeed, in a market-driven phase of the automotive industry.

TECH–8. Check your estimate of how a domestically produced (U.S.–owned companies) passenger car compares today and will compare in 1990 and 1995 with imported *German* vehicles.

	U.S. Passenger Car Versus German Vehicle		
	Higher Quality	About Same	Lower Quality
Fit and Finish			
Today	2%	27%	71%
1990	8	65	27
1995	17	71	12
Basic Structural Integrity of Body and Chassis			
Today	7	47	46
1990	12	65	23
1995	16	72	12
Engine and Drivetrain Integrity and Durability			
Today	16	34	50
1990	20	58	22
1995	23	64	13
Maintenance Requirements			
Today	45	43	12
1990	39	52	9
1995	38	56	6
Corrosion Resistance			
Today	33	54	13
1990	33	64	3
1995	35	63	2
Ride and Comfort			
Today	42	25	33
1990	37	45	18
1995	33	55	12
Styling			
Today	38	39	23
1990	42	48	10
1995	40	55	5
Handling			
Today	3	16	81
1990	6	48	46
1995	8	62	30

U.S. Passenger Car Versus German Vehicle

	Higher Quality	About Same	Lower Quality
Safety			
Today	29%	54%	17%
1990	24	68	8
1995	23	70	7
Total Car Reliability			
Today	14	43	43
1990	12	71	17
1995	19	74	7
Fuel Economy			
Today	25	44	31
1990	26	61	13
1995	28	64	8
Driveability			
Today	13	39	48
1990	11	66	23
1995	15	72	13

Selected Edited Comments

U.S.-European comparisons more difficult due to price segment difference (vis-a-vis U.S.-Japan). On a price-equivalent basis almost every category moves a notch in U.S. favor.

U.S. companies are copying German technology.

German engineering will continue to lead the way toward new and innovative vehicles with exceptional features.

Discussion

This question was not asked in prior Delphis but with the growing importance of European imports and the trend to "Eurostyling," it seems appropriate to address one of the leading producing nations on the Continent.

Comparisons of German and U.S. made cars show the German vehicles receiving higher quality ratings on fit and finish, engine and drivetrain integrity, durability, handling (with a very superior 81% to 3% lead), total car reliability, and driveability. U.S. passenger cars are shown as leading the German passenger cars on maintenance requirements, corrosion resistance, ride and comfort, styling, and safety. As with Japanese and American comparisons, the German and American car ratings converge in the forecasts so that "about the same" is the leading comparative evaluation for future models.

Discussion of Panelists' Comments

As indicated, U.S. versus European generic comparisons are more difficult (than U.S. versus Japanese) because of the wide range of quality and price of European products.

Comparison of Vehicle Manufacturer and Supplier Panelists

The comment in the comparable section of Tech–7 also applies here.

Strategic Considerations

See "Strategic Considerations," Tech–7.

Additionally, as new "quality" demands emerge in the marketplace, flexibility or adaptability on the part of the German automotive industry to these demands may be crucial to success.

TECH-9. In general (excluding inertia-weight-class crises), what is the value (in current dollars) per pound of weight saved to a vehicle manufacturer? What will it be in 1990 and 1995? (*In constant 1986 dollars*, that is, without adjusting for inflation.)

	Value per Pound Saved	
	Median Response	Interquartile Range
Today	$1.25	$1.00/1.40
1990	$1.50	$1.25/1.70
1995	$1.75	$1.50/2.00

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
VALUE PER POUND SAVED TO VEHICLE MANUFACTURERS

	Forecast for 1990 at the Time of the Survey			
	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Original Reply	$1.25	$2.00	$1.25	$1.25
Indexed to 1986 Dollars	1.86	2.41	1.37	1.25

Selected Edited Comments

Assuming no fuel shortage.

For us this is highly variable depending upon how close we are to our inertia weight class increment.

If CAFE is maintained at maximum level of 27.5 mpg.

Related to cost savings in other components due to weight reduction compounding.

Discussion

The value to vehicle manufacturers of weight saved is estimated at $1.25/lb. today and forecast to increase to $1.50/lb. in 1990 and $1.75 in 1995. There is relatively broad interquartile ranging suggesting that opinion varies on the value of weight reduction.

Discussion of Panelists' Comments

Comments point out the significant relationships of weight to fuel cost and government regulation.

Comparison of Vehicle Manufacturer and Supplier Panelists

The median dollar value for pound of weight saved projected by the vehicle manufacturer panelists is consistently lower than the combined median on all dates surveyed. The OEM panelists forecast $1.00 for every year through 1995; the suppliers forecast $1.00 for today and $1.50 for 1995. The lower end of the interquartile range for both groups is also consistently less than the combined totals, ranging from $0.60 to a high of $1.00.

Comparison of Replies to MAT-2

As is apparent from the following table, the Materials panelists suggest a significantly lesser value per pound of weight saved than do the Technology panelists. The interquartile ranges for the Materials panel forecasts are considerably broader than the interquartile ranges for Technology forecasts. This would indicate a notable lack of consensus. The upper quartile ranges are more consistent with the Technology forecasts. However, previous Delphi III Materials forecasts and the comments of the present Materials panelists support the Mat-2 median responses and merit consideration.

Materials Panel: Value per Pound Saved

	Median Response	Interquartile Range
Today	$0.50	$0.25/1.00
1990	0.55	0.33/1.25
1995	0.75	0.36/1.75

Trend From Previous Delphi Surveys

In 1979, the median forecast for 1990 was $1.25. The 1990 prediction increased to $2.00 in 1981, but declined to $1.25 in 1983 and in the current survey. When adjusted for inflation, the 1979 forecast (for 1990) at 1986 prices was $1.86; this increased to $2.37 in 1981 but dropped substantially to $1.35 in 1983 and decreased further to the current level of $1.25 (see trend table on previous page).

Strategic Considerations

If the value of a pound of weight saved becomes too low to be significant, the impact on the use of substitute materials could be very large. The declining value-per-pound trend appears to correlate with moderating expectations for the use of lightweight materials and consumers' reduced concerns for fuel economy. Of course CAFE standards still place an important burden on the manufacturers to improve fuel economy. Lightweight materials must still be considered. Question Tech-3 provides a view of the relative importance of fuel economy improvement factors, including lightweight materials.

The past importance of meeting CAFE inertia weight classes is still true today although there has been a change in the size of the classes. If a manufacturer is just above a given weight class boundary, the value of a pound of weight saved can be considerably more than if the weight is just below it.

TECH-10. In view of changing passenger car configurations, downsizing, and material changes, what impact do you see on accident repair costs (for body/chassis and body exterior damage) over the next decade?

	Percent Change (If any)			
	Body Structure Damage			
	Median Response		Interquartile Range	
Percent of Respondents Expecting Repair Cost	1990	1995	1990	1995
Increase: 27%	5%	10%	5/10%	5/15%
Same: 21%				
Decrease: 52%	−10	−20	10/20	10/25
	Body Exterior Damage			
Increase: 43%	10%	15%	5/10%	10/20%
Same: 12%				
Decrease: 45%	−20	−20	10/20	10/30

Selected Edited Comments

More and more of the damaged components will routinely be replaced rather than repaired. Cost will therefore increase as each "handler" of a component, i.e., wholesaler, distributor, etc., seek to profit from the transaction.

Movement toward modular cars with components bonded instead of bolted together will have a significant impact on future repair costs.

Plastic body panels, with proper education on repair procedures, will reduce damage cost.

Fewer repairs, more parts swapping and totaling by insurance companies.

I believe use of FWD and more sophisticated drivetrains, braking systems, and suspensions will increase the cost of body/chassis structure. However, increased use of plastic, easily replaceable skins should reduce exterior panel damage costs for which a high percent today is labor.

Decrease in repair costs due to impact of plastic exterior and separation of exterior panels and structure.

Less damage (or no damage) in many cases with plastic body panels.

Discussion

Repair cost trends are generally seen as favorable, with over half the respondents forecasting a decrease in the cost of body structure damage, and almost half, or 45%, predicting a decrease in the cost of body exterior damage. Offsetting the latter prediction, however, is an almost equally large forecast at 43% that the repair cost trend for body exterior damage will increase. Considering the time span of the forecast, the range of percentage change expected, whether an increase or a decrease, is modest at 5–20%. The interquartile demonstrate a reasonably good degree of consensus.

Discussion of Panelists' Comments

Comments suggest that the major reasons for the forecast cost trends are changing repair procedures, with an increased use of remove and replace, and changing materials.

Comparison of Vehicle Manufacturer and Supplier Panelists

Replies are comparable but supplier panelists are more optimistic than manufacturer respondents regarding cost trends in body structures and less optimistic with respect to exterior damage cost trends.

Trend from Previous Delphi Surveys

The repair cost trend of the present Delphi IV shows a dramatic reversal from the trend forecast in the previous Delphi III. In 1983 three-quarters of the respondents expected repair costs to increase over the next decade, with a 15% median percent cost increase by 1992. In the present Delphi IV, only 27% of the respondents forecast a repair cost increase, with a 5% median percent increase for body structure damage for 1990 and a 10% increase forecast for 1995. With respect to body exterior damage, 43% of the panelists forecast an increase in accident repair costs projecting a 10% and 15% increase for 1990 and 1995, respectively.

Concommitantly, only 7% of the Delphi III panelists in 1983 forecast a decrease of −10% for 1992; whereas approximately one-half of the Delphi IV panelists forecast a decrease of −20% for both body structure and exterior damage repair costs by 1995.

Strategic Considerations

The fact that most respondents do *not* see major increases in repair costs suggests that this important area of the automotive industry is under control.

Furthermore, reduced repair cost for the body structure is supported by the panelists in contrast to the mixed expectations for body panels. It is clear that the plastics/steel exterior issue is an important factor in the mixed results.

TECH-11. 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.

	Degree of Influence		
	High	Medium	Low
1. Quality	89%	11%	0%
2. Foreign competition	82	18	0
3. Market demand	71	22	7
4. Cost of manufacture (non-labor)/Manufacturing and assembly considerations (CIM)	68	29	3
5. Labor cost	56	36	8
6. Styling	51	43	6
7. Durability	50	42	8
8. Performance	45	51	4
9. Development and availability of new materials	44	44	12
10. Sourcing considerations	41	41	18
11. Comfort	37	58	5
12. More efficient powertrain	36	57	7
13. Integrated vehicle systems	31	44	25
14. Safety	31	53	16
15. Aerodynamics	26	60	14
16. Weight	19	68	13
17. Fuel economy	23	67	10
18. Self-diagnostics	15	49	36
19. Artificial intelligence systems	6	34	60

MEDIAN FORECASTS FROM TWO DELPHI SURVEYS
FACTORS IN LIGHT-DUTY VEHICLE DESIGN

	Ranking by Degree of Influence	
Factors	1983* Delphi III	1986 Delphi IV
Quality	1	1
Foreign Competition	2	2
Market Demand	8	3
Cost of Manufacture (non-labor)	4	4
Labor Cost	3	5
Styling	5	6
Durability	6	7
Performance	7	8

*Adjusted to 1986 factors list.

Selected Edited Comments

Fuel-cost effect determined by fuel price and federal regulations.

Engineering, performance, and reliability/durability will play a larger role: dollar value vs. price and styling.

Quality is rated medium only because it will be a given. Comfort is primarily a factor in small car packaging.

Self-diagnostics necessary due to electronic complexity.

There is no such thing as "non-labor"—your material is your supplier's labor cost; we have a labor content and labor cost problem—period.

Discussion

This question lists nineteen design factors ranked on the percentage of respondents indicating a high degree of influence for each factor. It is no surprise that quality, foreign competition, and market demand are at the top of the list. But the position of safety, vehicle weight, and fuel economy near the bottom require some consideration.

We interpret these relationships to indicate that recent first-priority design efforts to improve safety, vehicle weight, and fuel economy have essentially exhausted the potential for significant advances in these areas.

Comparison of Vehicle Manufacturer and Supplier Panelists

Replies are comparable with the exception that manufacturer respondents foresee higher importance for: sourcing considerations, market demand, and less influence for aerodynamics.

Trend from Previous Delphi Surveys

The opinions of the panelists regarding the relative degree of influence that a number of factors have on light-duty vehicle design have remained remarkably consistent from Delphi III through Delphi IV. Quality and foreign competition have remained solidly the number one and number two factors suggested by the panelists. The only striking difference between the two Delphis is the ranking of market demand. Market demand rose from 1% of total responses in Delphi III to 71% of high-degree-of-influence responses in the current Delphi. This clearly demonstrates the current awareness of the increasing importance of market demand for both the OEM and supplier segments of the industry.

Strategic Considerations

It is clear that the higher rated items are not optional for any manufacturer or supplier that expects to be a long-term industry participant. Broad product considerations are rated more highly than those related to more narrowly defined factors. The results suggest the years ahead will be extremely competitive for all. There is a perception that the market is mature with slowing demand and increasing competition. Also there are growing expectations for a downturn in the business cycle. Many of the factors could be combined under "Market Demand." Cost and quality are entry requirements to even begin to participate in the marketplace of the future.

TECH-12. *The following is a two-part question.*

TECH-12A. Do you foresee a trend toward more or less U.S. government regulation of the automobile industry in the following areas during the 1990s?

	Government Regulatory Trend		
	More	Same	Less
1. "Lemon Laws"	56%	38%	6%
2. Diesel Engine Emissions	53	39	8
3. Passenger Restraints	50	44	6
4. Product Liability	49	40	11
5. International Trade	49	45	6
6. Safety	36	60	4
7. Noise	23	65	12
8. Damageability	19	62	19
9. Corrosion	14	66	20
10. Spark-Ignited Engine Emissions	14	76	10
11. Fuel Economy (CAFE)	8	56	36

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
TREND IN GOVERNMENT REGULATIONS

	At the Time of the Survey, Predictions for the:			
	1980s			1990s
Expectations for Less Regulation in:	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Fuel Economy	0%	37%	32%	36%
Gasoline Engine Emissions	25	41	29	10
Diesel Engine Emissions	57	42	31	8
Safety	5	39	21	4

Selected Edited Comments

U.S. government is not the cause of product liability problem.

Recently reported loss of ozone layer in atmosphere and rising world temperature (greenhouse effect) will stimulate another round of emissions control legislation.

With low fuel prices, some form of fuel economy regulation will be required; however, direct market-acting taxes (e.g., on gas guzzlers) are far better than CAFE. Product liability and lemon laws will be larger issues, but specific laws and regulations, per se, won't increase. Instead existing structure will handle the load (e.g., tort law, class actions).

With the number of lawyers practicing in this country, I don't see any potential for less regulation. For the same reason, I think some categories will see more because they fall under the "consumer protection" umbrella.

Obviously, this whole issue highly depends on the federal administration in power.

More government intervention in the area of international trade would only further restrict a free economy and push the U.S. economy much closer to a controlled or manipulated economy. However, some short-term regulation may continue to be necessary if for no other reason than the high labor cost differences between the U.S. and developing countries, and our resulting high standard of living.

With new engine and car programs in place, CAFE should be a non-issue by 1990. Corrosion of new cars will also be a non-issue because cars will be good for 10+ years.

Discussion

Respondents expect more, rather than less, government regulation of the automobile industry during the 1990s. Among the eleven regulatory factors evaluated, 80% or more of the respondents expect the same or increased government regulations in ten of the categories while "only" 64% forecast the same or more controls on fuel economy. As discussed earlier, unpredictable factors can have a major impact on most of these Delphi forecasts. For example, fuel economy—ranked last here because government objectives have been or shortly will be achieved—could quickly rise to first place if there is another major intervention in oil supplies.

Discussion of Panelists' Comments

As indicated in the trend table above and in the comments section, panelists are not optimistic about overall reductions in government regulations, and their comments bear this out. However, our understanding of future automotive developments in the U.S. support the view, shown in the last comment, that CAFE may not be an issue by 1990. Such a development will be, of course, heavily dependent on political and international considerations.

Comparison of Vehicle Manufacturer and Supplier Panelists

Both groups agree that there is little chance of less regulation.

Trend from Previous Delphi Surveys

There are limited expectations for reduced government regulation. Only in the category of fuel economy do we find as many as 36% of the respondents forecasting less regulation during the 1990s. At the time of the 1981 survey there was some indication of growing hope that government regulations could be lessened, but it is clear from the results of the latest survey in 1986 that, except for fuel economy, these expectations have diminished. See trend table above.

Strategic Considerations

The prudent manufacturer and supplier must always plan for new areas of regulation. A "regulatory" future should be considered an integral part of every organization's strategic planning process.

TECH-12B. In the following areas, please indicate your expectations for possible future regulatory activities. These could be new regulations in previously unregulated areas or added regulations in areas already under regulation.

TYPE OR DIRECTION OF REGULATION FORESEEN

Emissions	Percent of Total Responses
Tightening of existing regulations or a moderate increase in established areas; more emphasis on enforcement and "in-use compliance" regulation. Twenty-two percent (22%) of this group specifically mentioned increased or tightening of regulations regarding diesel particulates and a legislated increased use of emission traps.	61%
No significant or little change and a continuation of existing regulations at present levels.	39

Representative Responses
Panelists cited the following for increased regulation: diesel particulates, emission audits, sulfur/acid rain; a reduction in hydrocarbons, ozone lead, and NOx; an adoption of California standards

Safety	
Increase in legislated regulatory activity. Of those forecasting increased regulatory activity a breakdown of specific areas is as follows: 38% specifically cited increased passive restraints (Federal Motor Vehicle Safety Standard 208) laws (seat belts, air bags) with 21% addressing the need for greater attention to passenger protection, including increased ability to escape from a damaged vehicle; 14% braking standards (including automatic braking and anti-lock braking systems); others included stiffer drunk driving laws and utilization of alcohol-related devices (7%); greater side impact and higher speed car-to-car impact protection (17%); anti-lacerative glass.	83%
Little or no regulatory activity or significant alteration of current standards.	14
Decreased regulation.	3

Representative Responses
Expect less regulation as car companies step up to the challenge.

Fuel Economy/CAFE	Percent of Total Responses
Expect CAFE requirements to remain stable with little or no activity.	58%
Decrease, relaxation, or de-emphasis of CAFE standards.	32
Increase in regulation.	10

Representative Responses
Holding at 27.5 mpg.
Status quo unless oil prices rise.
Lower CAFE if fuel is cheap.
Competition will cause "voluntary increases."
More rationality.
Drop CAFE by late 1990s.

Corrosion

No new regulatory activity or no significant change in existing standards.	73%
Increase in regulation.	18
The marketplace will serve as the deciding factor.	9

Representative Responses
No laws—the vehicle manufacturers will provide protection.
New five-year rust through.
2-5-10 year protection.
More like Germany.
Longer assurance—manufacturer liable.

Damageability

Increase in regulatory activity.	46%
Little or no activity.	35
Decrease or erosion of current regulations.	5
View this area as insurance dominated with efforts to reduce repair (insurance) costs.	14

Representative Responses
Increased emphasis with unitized construction.
Increased passenger protection.
Raise bumpers to 5.0 miles-per-hour.
Dollar amount with given impact.

Noise	Percent of Total Responses
Increase in regulation. Within the group of panelists who forecast an increase, 34% see that increase in stricter truck requirements. A single panelist projected a reduction in truck requirements.	38%
Little or no change in existing regulations.	58
Decrease.	4

Representative Responses
Interior and drive-by noise.
Lower decibel levels to operating vehicles.

Product Liability

Increase in regulatory activity.	64%
Less activity or the imposition of limits.	23
No change in existing regulations.	13

Representative Responses
Increased emphasis on manufacturer's responsibility-liability.
Manufacturers will be held more accountable.
Same or more burden on vehicle operators.
Consumer "protection."
Comprehensive revision of laws. Hopefully standardization.
Limits to liability.
Limitation per incidence.
Cap on non-monetary awards.
Regulations to reduce suits.
Forced by insurance costs.
Pendulum swinging to less.
Unsure but something will happen.

Passenger Restraints

Increased activity in passenger restraint legislation. Forty percent (40%) of this group specifically mentioned air bags.	90%
Less activity.	4
Some limits on liability of passenger restraints.	6

Representative Responses
Laws to force use of provided restraints.
Compliance and required new design field test.
Failsafe system—passive backups.
Friendly interiors.
Automatic seat belts.

Lemon Laws	Percent of Total Responses
Increased activity.	67%
No significant change in the status quo or additional activity.	26
Decreased activity.	7

Representative Responses
Federal no, state yes.
(Regional) state action only.
Continued extension to additional states.
Continued action at local levels.
Probably will increase due to higher vehicle purchase prices.
More demanding for manufacturers.
More pressure to fix problems the first time.
Consumer protection.
Manufacturer buy-back requirements.
Less need—improved vehicles.
If auto companies can meet challenge will be less.

International Trade

There will be some type of regulatory activity regarding international trade. Within this group, 35% specifically cited import restriction; 25% expect domestic content legislation.	77%
Stable atmosphere with no significant changes in current regulations.	23
Decrease.	0

Representative Responses
Some action on congressional level.
Increased specification.
Restrictions on components into U.S.-assembled foreign cars transplants.
Some type of local content.
Limiting imports.
Quotas, dumping, etc.
Import tariffs or checks and balances.
Blunted by U.S. plants transplants.
No new laws.
No mandatory local content legislation.
I hope not.

Others

Regulate plastic bodies for exterior flammability.

Unification with European Economic Community (EEC) activity in area of anti-lock braking.

Selected Edited Comments

Soaring insurance rates will force the issue of damageability and resurrect a call for passive restraints. U.S. OEMs have addressed safety and therefore no regulation is needed. However government-sponsored testing should continue.

This whole area of government regulation of commerce (internal and external) is very sensitive. Strong restrictions would certainly reduce lower-priced imports (a plus for balance of trade), but also reduce exports (a minus for balance of trade) as our trading partners react with their own protective regulations.

A total lack of U.S. government regulation would ultimately mean massive manufacturing sector job loss and business failure (in the U.S.) as foreign manufacturers flood the largest and richest consumer market in the world.

Discussion

This second part of question Tech-12 provided the panelists an open-ended question to identify the specific areas where change in the regulatory environment is expected to occur. Generally speaking, the responses to Tech-12B reflect those in Tech-12A, but considerably more insight is provided.

Comparison of Replies to MKT-2B

For the most part, Marketing panelists and Technology panelists are in agreement on the type and direction of regulatory and legislative activity in the areas surveyed. There are, however, a few notable differences.

Fuel Economy: Only 10% of the Technology panel forecast an increase in legislation in this area, whereas 26% of the Marketing panel expects the application of more stringent regulations.

Corrosion: Seventy-three percent (73%) of the Technology panel forecast no new regulatory activity or significant change in existing standards versus 59% of the Marketing panel.

Product Liability: With respect to increased regulatory activity in the area of product liability, 64% of the Technology panelists responded affirmatively versus 44% of the Marketing panel.

"Lemon Laws:" A significantly larger percentage (93%) of the Marketing panel forecast increased legislative activity with regard to "lemon laws" than did the Technology panel (67%).

International Trade: Of the total number of panelists responding to this area, 77% of the Technology panelists, versus 63% of the Marketing panelists, felt that there will be some type of regulatory activity regarding international trade. Twenty-three percent (23%) of the Technology and 37% of the Marketing panel forecast a stable atmosphere with no significant changes in current regulations.

Trend from Previous Delphi Surveys

See table regarding trends in government regulations, Question Tech-12A, page 38.

Strategic Considerations

There is little doubt that regulation in a variety of forms will be a part of the automotive industry future. A prudent manufacturer will closely study trends that might suggest the possibility of legislation and regulation. Those who feel the industry may be "all regulated out" are very likely to be surprised.

TECH-13. What percentage of U.S-produced passenger cars will use an integral frame or other design in model years 1990 and 1995?

		Median Response		Interquartile Range	
	Est. 1985	1990	1995	1990	1995
Integral Body/Frame or Unibody	92%	91%	86%	90/92%	80/90%
Space Frame/"Bird Cage"	1	4	10	3/5	5/15
Separate Body/Frame	7	5	4	5/7	2/5
TOTAL	100%	100%	100%		

Selected Edited Comments

Plastic skins (used with space frame) solve too many U.S. manufacturers' problems such as corrosion problems, cost of style change, and weight reduction to be anything but the material choice in the 90s.

Greater trend to separate "fashion" and "function," to skin for regional markets, etc.

Separate body frame cars will be old designs.

Space frame could be far greater. If we need to "niche" market off a few platforms, this is one way to accomplish it.

There are two significant issues about "space frame." Actually this classification should be named hybrid structure as the automotive applications are not pure space frame. (1) Separate chassis and body (appearance panels): This leads into new methods and efficiencies in body shop and assembly operations, including quality improvement. Also, new opportunities to promote, develop, and apply other materials than steel for design and manufacturing purposes. (2) This approach will allow continuous improvement of the chassis which will lead to reduced cost and improved reliability and quality.

Discussion

Clearly, the separate body frame construction is being phased out or at least restricted to a very few specialty models. Only 5% of U.S.-produced passenger cars are expected to have the separate body frame in 1990 and 4% in 1995. The birdcage design is expected to show modest growth to 4% in 1990 and 10% in 1995. Most cars will have the integral body frame or unibody.

The interquartile range consensus on these forecasts is very good.

Discussion of Panelists' Comments

Most of the comments support the space-frame construction method, but these should not detract from the overwhelming numerical vote for the integral body frame or unibody.

Comparison of Vehicle Manufacturers and Supplier Panelists

There is no significant difference between the forecasts of the vehicle manufacturers and suppliers.

Trend from Previous Delphi Surveys

In the previous Delphi III survey, it was estimated that the space frame or birdcage construction would represent 5% of the total in 1990. As shown here, this forecast has now dropped to 4%. The decline is not statistically significant, but what is significant is the lack of growth in this particular forecast (see Figure T-5 below).

Summary: TECH-13 through TECH-15

Figure T-5 summarizes integral frame design utilization as forecast in questions Tech-13, Tech-14, and Tech-15.

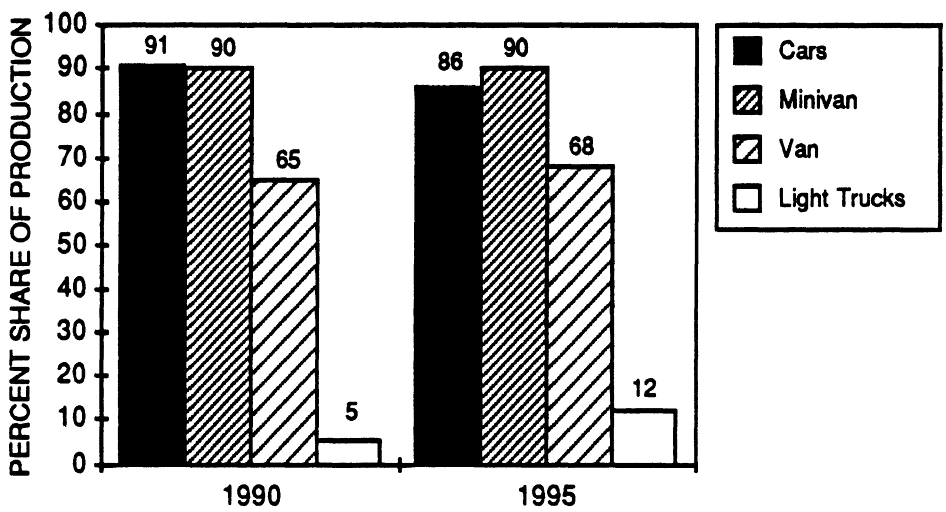

FIGURE T-5. U.S. Light-Duty Vehicles: Integral Frame Design

Strategic Considerations

The advantages of the space frame or birdcage construction method are becoming better known; with experience, some of its disadvantages are perhaps becoming apparent.

The integral body/frame is the choice for the majority of future U.S.-produced passenger cars, but on a percentage basis, significant growth is forecast for the space frame. This increase could lead to even more significant penetration in the latter part of the 1990s. Clearly, technological trends of this type must be watched closely, since the impact could be profound on many vehicle subsystems. A "breakthrough" is possible in the general area of vehicle structures that could cause a significant shift in the forecast in the mid nineties.

TECH-14. What percentage of U.S.-produced vans will use an integral frame or other design in model years 1990 and 1995?

	Median Response			
	Mini Van		Conventional Van	
	1990	1995	1990	1995
Integral Body/Frame or Unibody	90%	90%	65%	70%
"Bird Cage"	5	7	0	0
Separate Body/Frame	5	3	35	30
TOTAL	100%	100%	100%	100%
	Interquartile Range			
Integral Body/Frame or Unibody	70/95%	75/92%	40/70%	45/75%
"Bird Cage	0/10	5/15	0/0	0/5
Separate Body/Frame	0/20	0/10	30/60	20/50

Selected Edited Comments

Rigidity vs. weight is a problem with vans, and steel appears to have an edge in the compromise. However, look for plastic body parts in the form of doors, tailgates, hoods, cowlings, etc. A conventional van may have 60% of the plastic content of a "bird cage" design.

Discussion

The mini van is expected to have about the same construction mix as shown for passenger cars in the preceding question (Tech-13). Conventional vans are expected to remain at about one-third separate body frame construction. The consensus on these estimates is not tight. The interquartile range here is good for the mini van, but fairly broad on the conventional vans.

Discussion of Panelists' Comments

The single comment is a good summary of the trade-offs between steel and plastics.

Comparison of Vehicle Manufacturer and Supplier Panelists

There is no significant difference between OEM and supplier panelists.

Trend from Previous Delphi Surveys

In the Delphi II (1981), panelists forecast that 60% of vans would have the integral frame design in 1990. Three years ago, in Delphi III (1983), the 1990 forecast increased to 75% (see Figure T-5). However, these earlier forecasts did not differentiate between mini vans and conventional vans. Therefore, the separate forecast here of 90% for mini vans and 65% for conventional vans is in line with the previous forecast of 75%.

Strategic Considerations

At least one product presently in the design stage could determine the role of the space frame in small vans. This development should be watched closely. The relatively broad interquartile ranges suggest there is considerable uncertainty and that there may be several equally capable solutions to van structures.

TECH-15. What percentage of U.S.-produced light trucks will use an integral frame or other design in model years 1990 and 1995?

	Light Trucks			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Separate Body/Frame	95%	88%	90/97%	75/93%
Integral Body/Frame or Unibody	5	12	3/10	7/25
"Bird Cage"	0	0	0/0	0/0
TOTAL	100%	100%		

Discussion

Most light trucks will continue to use a separate body frame, but the percentage share is forecast to drop from 95% in 1990 to 88% in 1995 with the difference made up by the growth of integral body frame, or unibody. The interquartile ranges for the use of the integral body frame show a fairly wide spread of opinion.

Comparison of Vehicle Manufacturer and Supplier Panelists

The supplier panelists estimate lower percentages for separate body/frame, forecasting 90% in 1990 and 80% in 1995. The differences are evident in increased percentages for integral body/frame in both years.

Trend from Previous Delphi Surveys

Five years ago, the panelists forecast 45% integral frame designed for light trucks by 1990. Three years ago, the 1990 forecast was for only 20%. As shown above, the 1990 forecast has now declined to 5% (see Figure T-5).

Strategic Considerations

Most light trucks will continue to use a separate frame. In many, the "load-driven" designs of today are, in principle, likely to prevail at least through the next ten years. However, the potential for new thinking must not be ignored considering the importance of light trucks in the marketplace today.

TECH-16. There is a modest but significant trend toward the use of the space frame/ "bird cage" (Fiero) body design. What effect will this have on materials choice and overall vehicle design trends?

Effect on Materials Choice and Vehicle Design Trends	Percent of Total Responses
Increased usage of plastics, composites, and other non-steel skins and body panels	59%
Increased styling freedom/body style proliferation	27
Others: Increased use of adhesives Increase in modular construction Increased automated assembly with replacement of stampings Decrease in cost of tooling Decrease in cost of labor	14

Selected Edited Comments

The Fiero experience shows that the designer will have much greater latitude for design changes to address styling trends.

I'd expect major impact on materials by the mid-1990s as space frame itself becomes a composite material and body panels are attached by adhesives. This would affect only about 10% of car production at that point. As long as space frame is steel or aluminum and panels are fastened to frame (like Fiero), economic advantages not evident.

Paint and fastening systems will change. Plastics may be moldable in class A finishes soon. Also, adhesives may replace about one-quarter of the welds and all body trim fasteners.

The cage really becomes the framework for the soft body panels—as the choice of plastic parts grows, the need for such a frame will also grow.

Wide range of plastic "non-structural" panels. More flexible design possibilities for a given space-frame package.

"Bird Cage" frame will promote the usage of plastic body panels and will standardize automotive "super structures" allowing styling changes to impact only the outer skin of the vehicle.

A major impact. The use of space frame construction permits increased styling freedom (i.e., appearance changes). Because of this, materials will be chosen (in large part) for their ability to be adapted and/or processed without major tooling implications.

Concept lends itself to plastic body panels, automated assembly of panels to "bird cage," reduced labor cost (and related fringe benefits), and increased overall automation. Also adds credibility to GM10 concept of replacing old-fashioned assembly line with very flexible, automated assembly line incorporating computer-controlled, moving vehicle work stations.

Greater use of composite and SMC panels but will be limited to low-production-volume vehicles as it is today.

Increased use of plastics/composites for body panels. More variation in styling and model changes.

More plastics (RIM and compression molding) panels, more high strength steel space-frame usage.

More flexibility in design when using plastic panels—significant modifications for each model are possible with cheaper dies.

Plastic panels must meet class "A" surface requirements. Bird cage will be made of plastic composites.

Should revolutionize tooling/marketing/design. Ideally, separate fashion from function.

Significant shift from steel to composite exterior body panels. Some shift from steel interior panels and structural members to composites.

Significant effect in choosing cosmetic, non-structural body panel materials. Secondary effect on space-frame construction (rolled sections and tubes replacing stampings).

There should be new materials developed as well as new processing in the plants. This should give designers more flexibility in their designs.

The obvious effect will be to increase usage of plastics for the skin. Considerable progress, however, must be made in the area of weight efficiency as the Fiero is not efficient. Use of high strength steels and refinement of the structural design should enable weight reductions; however, integral body designs with stressed steel skins will remain the most weight effective.

This construction will use a larger quantity of plastic exterior surface panels. The change will be driven by styling flexibility, freedom from cosmetic corrosion deterioration, and damage resistance.

More use of fiberglas and laminated skin; lighter weight construction: more plastic, lighter gauge metal sheet and aluminum; designs will tend to be more sporty, even for non-sport models.

It will lead to an increase in light weight aluminum or HSLA steel in space frames.

It will probably result in the use of more moldable, low tooling cost exterior panels in order to optimize the potential for differences in appearance from model year to model year. It should also result in utilization of materials of lighter weight for exterior panels to offset what, till now, appears to be a heavier weight basic design.

More frequent and less expensive face lift. Greater product differentiations for "badge-engineered" vehicles.

More plastic and aluminum, aluminum to offset the added weight, plastic for easy skin changes.

More high performance materials, hang-on parts, and

Space frame allows extensive use of light metals or fastening systems. continuous-filament composites, but adaption will be retarded and may be prevented by product liability concerns over use of materials which absorb energy by fracture instead of by bending.

Discussion

Replies to this question indicate the range of opinion that would be expected from the numerical forecast made in the immediately preceding questions, Tech-13 through Tech-15.

Strategic Considerations

It is becoming clear that no technology should be ignored. Progress in adhesives, new plastic-based materials, and a resurgence in innovative approaches to steel panels suggest that the ultimate materials selection is far from clear. Clearly, manufacturing considerations are of extreme importance as are characteristics that will permit manufacturers to shorten lead time and create product differentiation.

TECH-17. 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 in the following years?

	Median Response			
	Integral Body/Frame		Space Frame	
Material Mix	1990	1995	1990	1995
Steel	90%	80%	85%	70%
Aluminum	5	10	10	15
Composites	5	10	5	15
TOTAL	100%	100%	100%	100%
	Interquartile Range			
Steel	90/95%	80/85%	75/90%	60/80%
Aluminum	4/7	5/10	5/10	10/20
Composites	2/5	5/10	5/10	10/20

Selected Edited Comments

Space frame design has greater requirement for rigidity. Expense of plastic skin content will force costly aluminum out of the mix. All steel unibodies will tolerate higher aluminum content due to lower cost of a steel skin and the ability of aluminum to be finished (coated/painted) like steel.

Adaption of plastics in safety-related components, such as frame/structure, will be much slower than in exterior panels.

Space frame will result in plastic fenders, door outers, quarters, deck, and probably hood.

Costs will dictate use of steel as energy and aluminum prices increase.

Discussion

Aluminum and composites are forecast to make modest inroads on the use of steel in both integral body/frame and space frame designs. Interquartile ranges show a fair degree of consensus.

Discussion of Panelists' Comments

In general, the comments are *not* supportive of the growth forecast in the use of materials other than steel.

Comparison of Vehicle Manufacturer and Supplier Panelists

Forecasts for material mix of two groups are essentially identical.

Comparison of Replies to MAT-14

It is clear that in the material mix for 1990 and 1995, integral body/frame, the Technology panelists forecast a higher percentage of composites to the disadvantage of steel. In the space-frame designs, the Material panelists forecast a higher percentage of steel than the Technology panelists. See table below.

	1990 Forecast		1995 Forecast	
Integral Body/Frame	Technology Panel	Materials Panel	Technology Panel	Materials Panel
Steel	90%	95%	80%	85%
Aluminum	5	4	10	10
Composites	5	1	10	5
Space Frame				
Steel	85%	90%	70%	80%
Aluminum	10	7	15	10
Composites	5	3	15	10

Strategic Considerations

The emergence of both aluminum and composites as candidates for basic structural components is significant. Developments must be watched very closely. A modest role for any new material could lead to explosive growth if advantages are substantial. Technical innovation is being prompted by new material technology.

TECH-18. Consider the following list of automotive components and indicate the percentage of each likely to be made in 1990 and 1995 from either steel or plastics (in various forms).

	Median Response			
	1990		1995	
Automotive Component	Steel	Plastics	Steel	Plastics
Hood	80%	20%	70%	30%
Roof	93	7	85	15
Doors	90	10	75	25
Rear Deck	85	15	60	40
Front Fenders	80	20	67	33
Rear Quarter Panels	90	10	70	30
	Interquartile Range			
Hood	75/90%	10/25%	50/80%	20/50%
Roof	90/98	2/10	70/90	10/30
Doors	80/95	5/20	60/88	12/40
Rear Deck	70/90	10/30	50/80	20/50
Front Fenders	70/90	10/30	50/75	25/50
Rear Quarter Panels	75/94	6/25	50/80	20/50

Selected Edited Comments

Plastics are difficult to apply to integrated body parts like rear quarter panels but work well for discrete panels. Doors are a weight/strength compromise.

Space frame vehicle would be majority plastic but would be small percentage of the total vehicles produced.

Strength problems with plastic doors will be solved by 1995 so that federal crash requirements may be met.

Space frame will result in plastic fenders, door outers, quarters, deck, and probably hood. Also, any components with volume less than 25,000/year will be plastic.

Contingent upon space frame applications.

Strength in side impact is an issue.

The biggest issue is getting "old" thinking to accept the new plastic materials as equal or better than steel. Need to improve paintability of plastic parts also.

Plastics is capacity-limited in 1990.

Discussion

Previous Delphi studies of materials usage have forecast a steady decline in the use of ferrous materials and an increasing use of plastics and other lightweight replacements. However, the issue of plastic versus steel has heated up to such an extent that this new question directly measures that contest. The results show that the future calls for a continued erosion of steel usage by plastics.

The results of the question indicate that respondents were, to some extent, "voting" between steel and plastics and as this was the major intent of the question, we are satisfied with the results. However, aluminum is a possible material for some of these applications and would prevent the percentages from totalling 100% as they do here.

Note that increases in the percentage of plastics-use represent growth of at least 50% (for hoods) and as much as 20% (rear-quarter panels) between 1990 and 1995. However, the interquartile ranges show a wide range of predictions. These are particularly notable in the plastics forecast. The hood, for example, shows a range from 10% to 25%—a 2.5:1 ratio. The rear-quarter-panel interquartile range of 6% and 25% reflects a more than 4:1 difference of opinion. Such a lack of consensus suggests low precision in these forecasts, but the general trend toward more plastic usage is still evident. Note, for example, that the lower quartile forecast of 10% plastics for roof panels in 1995 is equal to the 1990 high-end quartile forecast. Nothing in these figures suggests a reversal of the trend to more plastics at the expense of iron and steel.

Discussion of Panelists' Comments

Comments are generally supportive of the numerical forecast and suggest some of the important factors to be considered in planning any transition from steel to plastics.

Comparison of Vehicle Manufacturer and Supplier Panelists

Forecasts by the two groups are close for each component and frequently identical.

Strategic Considerations

Recent strong efforts by the steel industry to slow these trends have, in our opinion, been considerably successful. However, these data suggest that the struggle is far from over.

It is becoming clear from international data that the efficiency with which the U.S. fabricates steel is considerably less than it should be. That is, the relative costs of our steel fabrication are still too high. It is imperative that manufacturers not attempt to solve a management problem in steel processing with substitution of plastics if that will lead to a sub-optimum solution in comparison to competition. Emphasis must be placed on comparing materials with world-class state-of-the-art processing. An imponderable in the materials battle is the role of the customer. At the present time the consumer does not appear to be placing value on the particular materials used in today's products. However, this could change and could immediately skew the materials picture in the future.

TECH-19. What chassis subsystems produced in commercial quantities (30,000+ units) in the model years 1990 and 1995 will be controlled electronically?

Chassis Subsystems Electronically Controlled

1990:	Percent of Respondents
Anti-lock braking systems	89%
Active suspension (height control)	52
Shocks (ride control)	34
Power steering	30
Automatic transmission	26
None	7
Others:	
Roll control	
Vehicle anti-theft	
Power distribution to wheels (anti-slip)	
Rear-wheel steering	
Speed control	
Service monitoring	
Four-wheel drive	

1995:	
Active suspension	60%
Power steering	30
Four wheel steering	20
Anti-lock braking systems	15
Automatic transmissions	15
Traction control	10
Others:	16
Tire pressure	
Engine mounts	
Spin control	
Rear steering	
Speed control	
Throttle control	
Entry/exit control	
Manual transmission	
Collision avoidance	

Discussion

Technology panelists forecast a wide variety of electronically controlled subsystems will attain commercialization in 1990 and 1995. Antilock braking was the overwhelming winner in 1990 followed by active suspensions, electronic ride control through shock absorber rate change, automatic transmissions, and power steering. By 1995 active suspensions lead the list followed by anti-lock braking systems, power steering, electronic control shocks, and automatic transmissions. Where features (such as anti-lock braking) are shown at a lower percentage in 1995 compared to 1990, it does not diminish the forecast for this technology, but indicates that the feature is expected to attain commercialization earlier. Also, since some of the technologies perhaps have already attained commercialization, it may be interpreted that mention would reinforce expectations in the future. With respect to the leading technologies identified in this question, we have followed with a subsequent question aimed at identifying percentage market penetration in the years 1990 and 1995. See Tech-24.

Strategic Considerations

A wide variety of advanced features based on electronic technology is anticipated in the next ten years. While certain items received strong support, those that received modest mention are worthy of serious consideration. Electronics applied to a broad variety of vehicle features supports the high value of electronic componentry that analysts have predicted for the future.

A further consideration of great importance is the market acceptance of these features. The price/benefit or value analysis that the customer will perform is probably critical to the future of most advanced technologies. There is no question that high-tech, top-of-the-line models will incorporate much of this technology. How far "downmarket" these will propagate is another question. In many respects, the electronics will be transparent to the customer who is only looking for the basic function such as power steering or automatic transmission.

TECH-20. As part of the passenger car redesign process, new brake designs may be considered which could include increased or decreased use of both disc or drum brakes. What percentage of U.S.-produced cars, light trucks, and vans will use rear-disc and/or rear-drum brakes in 1990 and 1995?

Percent Usage: Rear Brake Type

	Passenger Cars		Light Trucks		Vans	
	1990	1995	1990	1995	1990	1995
Median Response						
Rear Disc Brakes	20%	40%	5%	15%	10%	20%
Rear Drum Brakes	80	60	90	85	90	80
Interquartile Range						
Rear Disc Brakes	10/30	20/55	1/10	5/25	2/15	10/35
Rear Drum Brakes	60/90	45/80	90/98	75/95	80/97	65/90

MEDIAN FORECASTS FROM THREE DELPHI SURVEYS
PASSENGER CAR REAR BRAKES IN 1990

	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Rear Disc Brakes	30%	30%	20%
Rear Drum Brakes	70%	70%	80%

Selected Edited Comments

Rear disc will increase *unless* anti-lock (ABS) systems are mandated.

Discussion

This question relates only to the use of disc or drum brakes on the rear of passenger cars, light trucks, and vans. It became obvious by the time of the previous study, Delphi III, that use of drums on the front wheels was being phased out.

These data, from Delphi IV, suggest that disc brakes are beginning to take hold on rear wheels also. The median forecasts show the use of disc brakes on the rear increasing to 40% on passenger cars in 1995, 15% on light trucks, and 20% on vans. The interquartile ranges for these medians are fairly broad, suggesting that actual usage may vary from the median responses.

Discussion of Panelists' Comments

The single comment raises an important issue to be kept in mind when estimating patterns of brake usage.

Comparison of Vehicle Manufacturer and Supplier Panelists

Forecasts are comparable but manufacturer respondents see slightly more retention of rear drum brakes than do the supplier respondents.

Trend from Previous Delphi Surveys

This is the third survey in which we have asked respondents for a 1990 forecast of drum and disc usage on rear brakes. The forecast for the use of disc brakes on the rear wheels of passenger cars in 1990 were 30% in the previous two Delphi surveys but have dropped to 20% in this survey. This change is significant because it suggests that although the upward trend to rear disc brakes continues, it may not be as steep as once thought.

Strategic Considerations

With this modest expected trend toward rear disc brakes it must be recognized that there are considerable hardware variations between the two brake systems which could represent increased business opportunity for some suppliers and reduced opportunity for others. Any technological shift such as this can be viewed either as a threat or an opportunity, depending on one's capabilities.

TECH-21. What significant developments in the chassis/suspension areas are likely to be introduced in commercial quantities (30,000+ units) in U.S.-produced passenger cars by the 1990 and 1995 model year?

Chassis/Suspension Developments

1990:	Percent of Respondents
Anti-Lock Braking Systems (ABS)	49%
Active/Adaptable Suspension	34
Electronic Power Steering	16
Composite Springs	11
Four-Wheel Drive	11
Advanced Wheel/Tire Concepts	9
Continuously Variable Transmission (CVT)	7
Four-Wheel Steering	7

1995:	
Electronically Controlled Active Suspension	56%
Four-Wheel Steering	29
Anti-Lock Braking Systems	23
Electronic Power Steering	23
Composite Springs	12
Continuously Variable Transmission (CVT)	7
Advanced Wheel/Tire Concepts	7
Traction Control (anti-spin)	7
Unspecified Electronic Controls	7
Four-Wheel Drive	6
Other	6

It was necessary to abbreviate the forecasts for the purpose of integrating the many responses of the panelists into comprehensive groupings. In order to provide as much insight as possible into the thoughts of the panelists, "Representative Responses" are provided in lieu of "Selected Edited Comments."

Representative Responses

1990

"Smart" suspensions for ride control and smoothness.
Adaptive handling systems to tailor ride.
Controlled or adjusting suspensions.
Ride height control-leveling.
Adjustable damping.
Air-oil suspension.
Widespread use of independent rear suspension.
Manual adjusted suspension control.

Increase in four-wheel independent suspension into all body styles and vehicle sizes ... the future standard.
Composite materials for suspension system will come into much greater use.
More composite leaf springs.
Sulcated composite springs replacing steel springs in certain car lines.
Wholesale use of plastic-fiberglas rear leaf springs.
Higher reliability tire, wheel, valve system.
Smart tires with information and self-healing.
Higher mileage, run-flat tires.
Integrated tire, wheel, hub.
Indirect servo-throttle system.

1995

Active air/hydraulic suspension systems.
Driver-controlled suspension stiffness.
Growing use of air suspension and on-board computer "leveling" and adjustment of vehicle's stance on the road to enhance aerodynamics and reduce drag.
Adjustable ride-control suspensions.
Variable-rate (electronically) computer-aided ride systems.
Modular steering and suspension at each wheel.
Fully electronic steering and braking.
Use of composite plastic components.
Composite torsion bars.
More non-metal springs.
Composite control arms.
Use of composites for chassis/suspension areas in several car lines.
More use of lightweight materials.
Modular steering and suspension at each wheel.
Redefined "steering column"
Electronically controlled, electrically driven steering.
Electric boost steering.
Servo steering.
Electronically controlled transmission and engine combination.
Plastic wheels.
Smart tires.
Four-wheel drive will become more common.
Automatically selectable four-wheel drive.
Electronic controls on vehicle dynamics parameters.
More integration of systems.
Advanced navigation systems.
Passive four-wheel steering—Japanese systems copied by U.S.
First there will be integration of suspension electrically with brakes, steering, and driveline for anti-dive, anti-roll, and compensation for load transfer on acceleration.

Discussion

A wide range of technological developments are expected in the chassis suspension area in 1990 and 1995. It is evident that advanced technology components are expected to move rapidly to the forefront in this area of the vehicle. Some items such as composite springs that, to a certain extent, have already attained commercialization are reinforced by the survey. In some cases, panelists will indicate commercialization first in 1990 and others with a given feature in 1995. Consequently, the data may not seem consistent. For example, electronic power steering is forecast by 10% of the panelists in 1990 and by only 7% in 1995. The inference is that more of the panelists think electronic power steering will first attain commercialization, according to our definition of 30,000 units, in 1990 than believe that this will occur first between 1990 and 1995. Consequently, direct quantitative use of this information is not as useful as the general level of expectations of the technologies.

Strategic Considerations

While the data in this question certainly do not provide actual commercial percentage rates for the technologies listed, it is a strong indication that the next ten years will bring a major onslaught of new chassis suspension features. The specific penetration rates in the various years are explored in a subsequent question for most of the technologies suggested. See Tech-24.

TECH-22. Indicate major shock absorber/damping system changes that are likely to be introduced in commercial quantities (30,000+ units) in U.S.-produced passenger cars by the 1990 and 1995 model year.

Shock/Damping System Changes

1990:	Percent of Respondents
Electronically/Driver-Controlled Shocks/Damping	78
Air Springs	13
Oil Suspension	8.5
Composite Springs*	8.5
Modular Corners for Suspensions	4
Four-Wheel Independent Suspension*	4

1995:	Percent of Respondents
Electronically/Driver-Controlled Shocks/Damping	79
Active Hydraulic/Special Fluid Shocks under Active Control	21
Terrain Sensors	16
Integrated Spring Damping	8
Speed Sensors	4
Composite Material Springs*	4
Modular Corners for Suspensions	4

*See "Discussion" below.

Representative Responses

1990

Controlled air-bag suspensions.
Damping controlled by more factors than velocity.
Road profile-drive shock valving.
Optimizing controllers.

1995

Automatic damping control for "lifetime" shock.
Automatic four corner air suspension replacing "shock absorber."
Computer-controlled damping of sprung mass.
Integrated shock absorber.
Suspension without separate springs.
Rheological components under active control.

Discussion

We attempted to explore in some detail the shock/damping characteristics expected to emerge in commercial applications by 1990 and 1995. The overwhelmingly significantly factor is electronically/driver-controlled damping system. It is generally difficult to interpret all of the responses and aggregate them appropriately, but the lists clearly suggest rather substantial interest in a host of factors. The primary intent is to elicit suggestions of the emerging technologies. Some factors may be suggested even though commercialization is attained prior to the 1990 or 1995 model year, and in fact, in several cases have attained that level today. Also, several factors are not exactly appropriate to the stated question.

Strategic Considerations

It appears clear that some rather basic and fundamental changes are taking place in basic vehicle shock absorbers. While the extent of utilization of these technologies is not clear, it is evident that the suspension component manufacturers will be facing a much more technically sophisticated challenge in the years ahead. A further complicating factor is the potential for a much longer life in these more advanced components, which could have a serious impact on the long-range aftermarket opportunities.

A further challenge suspension manufacturers face is the development of suspension subassemblies or modules to meet the trend of modular construction. The new tier-one module supplier will be a key factor in technological developments. This "retiering" of industry is a trend of importance to all industry participants and extends to every component.

A most interesting technology that requires watching is electrorheological fluid-based damping systems that could become an integral part of active ride/handling control.

TECH-22A. What percentage of U.S.-produced passenger vehicles will utilize the following shock absorber/damping systems in the years indicated?

	Percent U.S.-Produced Passenger Vehicles			
	Median Response		Interquartile Range	
Shock Absorber/Damping Systems	1990	1995	1990	1995
Four-wheel independent suspension	25%	39%	10/35%	20/60%
Composite springs	10	20	5/15	10/30
Driver-controlled shocks/damping	5	15	5/10	10/20
Air springs	5	10	2/5	5/10
Oil suspensions	1	5	0/5	1/10

Selected Edited Comments

Air spring applications make a lot of sense when the styling of the vehicles and high-static deflection suspensions with variable wheel rates are concerned. A four-wheel-independent suspension is a matter of fact when we consider improvements in handling, side, structural shake qualities of the vehicles. Reduction of spring to unsprung weight ratios suggests the use of independent suspensions, especially on lightweight small cars.

Discussion

The response to this question will focus on basic changes expected in future suspension systems. Four-wheel independent suspensions are expected to be used in 25% of 1990 passenger cars, and this is expected to grow to 39% in 1995. Composite springs are expected to expand from 10% in 1990 through 20% in 1995. More modest expectations are evident for driver-controlled shocks or damping systems, air springs, and hydraulic or oil-based suspensions. The interquartile ranges on these various technologies are quite broad, indicating significant uncertainty on the part of the panelists.

Discussion of Panelists' Comments

While there is only one comment offered on this particular question it is thoughtfully constructed and important.

Strategic Considerations

With a variety of factors addressed in this question, a simple strategic consideration may not be appropriate. However, it is another indication of pending change in the industry. Continuing expansion of four-wheel independent suspensions to nearly 40% of the market in 1995 would suggest considerable opportunities of the manufacturers for these systems. However, at the same time, this means reduced opportunity for those who are currently producing solid-axle designs. A dramatic growth is anticipated in composites in springs as in many other parts of the vehicle, based on advanced plastics technology. Ultimately, the impact of all of these will be measured only as the customer acceptance is defined. One wonders where the break point will be between the higher-technology specialty vehicles and higher-volume, more commodity-type vehicles with respect to the application of these various factors. In most cases, they will apply largely to higher-tech vehicles. Ford is an exception since all new front-wheel-drive (FWD) programs since 1980 have had four-wheel independent suspension.

TECH-23. What percentage of U.S.-produced passenger cars will utilize independent rear suspensions in model years 1990 and 1995?

	Percent U.S.-Produced Cars With Independent Rear Suspensions	
Model Year	Median Response	Interquartile Range
1990	30%	25/30%
1995	50	40/60

Selected Edited Comments

U.S. will trail Europe in independent rear suspension (IRS) application, but precise number is difficult to forecast.

Independent rear suspension gives superior wheel control on chatter bumps and adds marketing hype.

Discussion

Expectations for U.S.-produced cars with independent rear suspension are very high with a forecast of 30% by 1990 and 50% by 1995. The interquartile ranges show a strong consensus of opinion on these predictions.

Comparison of Vehicle Manufacturer and Supplier Panelists

The OEM and supplier panelists gave identical median responses of 30% for 1990. The interquartile range of these two individual groups were even tighter than that of the combined. For 1995, however, supplier panelists expect that only 40% of U.S.-produced passenger cars will utilize independent rear suspensions, whereas the manufacturers forecast 55%. The interquartile range for the 1995 supplier forecast is such that the 40% projection could represent a majority of the supplier respondents.

Strategic Considerations

The significant growth forecast for independent rear suspensions suggests important new opportunities for its components but reduced opportunities for solid axle components. Since so many variations in independent rear suspension designs are possible, trends must be followed closely. The impact of new technology such as active ride control and active rear-wheel-steering could be significant on suspension design and should be monitored.

TECH-24. What percent of U.S.-produced passenger cars will have the following chassis/ suspension features by 1995?

Chassis/Suspension Features	Median Response	Interquartile Range
Anti-lock brakes	60%	50/75%
Lightweight structural components	50	30/55
Driver-selected ride/handling mode	20	15/30
Electronically controlled active suspension systems	20	10/30
Active four-wheel steering	5	5/10

Selected Edited Comments

Anti-lock brakes *could be* government mandated by 1995.

There are a lot of lightweight structural components now and near future. Percentage given is for cars which will use primarily composite material space frames.

Anti-lock brakes: government regulation may mandate this just as it did CAFE requirements in the '70s.

At the present time active four-wheel steering does not seem to be what it was claimed. To do it right, complex electronic controls are necessary. The value of it may not be very high.

Discussion

Anti-lock brakes are expected on 60% of U.S.-produced passenger cars by 1995, owing in part to parallel expectations of government regulations requiring these components.

Strategic Considerations

The primary new technological factors in the chassis area are covered in this question. While the interquartile range is reasonably broad for several features, the fact remains that we are on the threshold of a chassis technology revolution. In general, considerable value added will occur with each technology.

One may wonder what role market forces will play. We suspect they will be significant and the perceived cost/benefit relationship of each feature will be critical. Given the tremendous effort being applied by all the manufacturers and a number of the suppliers, technological breakthroughs can be expected in each area.

TECH-24A. What percentage of U.S.-produced passenger vehicles (cars, vans, and light trucks) will incorporate the following chassis/suspension features in the years indicated?

	Percent U.S.-Produced Passenger Vehicles			
	Median Response		Interquartile Range	
Chassis/Suspension Features	1990	1995	1990	1995
Anti-lock braking systems	20%	50%	10/30%	30/65%
Composite springs	10	20	5/15	10/30
Electronic power steering	5	25	2/15	10/40
Traction control (anti-spin)	5	20	3/15	10/40
Active suspension *ride mode**	5	15	3/10	10/20
Active suspension *handling mode**	5	10	2/5	5/15
Active four-wheel steering	1	5	0/5	4/10

*Mechanical/electrical.

Selected Edited Comments

[Referring to panelists' forecast of 50% anti-lock braking system by 1995:] This assumes that very substantial cost reductions occur. I believe that they will occur. The rate could go even higher when the safety aspects of the anti-lock braking system are better known.

Electronic power steering, composite springs, and most suspension package will be added to save weight, fuel, or ease manufacture. The anti-lock systems will become an accepted standard. Active four-wheel steering and handling mode suspension will be high-tech items.

Anti-lock braking could be mandated.

What is definition of active suspension? If we mean Lotus type, then 0% in 1990 and 5% in 1995. Figures above are for semi-active/adaptive.

During the last ten years (especially the last five years) the handling and ride qualities, tied in with structural integrity of the vehicle structures, have improved to such a high level of performance that active suspensions and active handling mode suspensions could only be introduced in high-tech image, expensive cars.

Discussion

This is an added second round question in response to the need to quantify application of various chassis-related technologies for 1990 and 1995. The median data suggest a rather strong growth on a percentage basis for all factors listed. Significant opportunities for future penetration are anti-lock braking expected in 50% of 1995 vehicles, electric/electronic power steering in 25% of these vehicles, and composite springs and traction or anti-spin control in 20% of vehicles by 1995. The interquartile range on most factors was relatively broad, indicating a substantial level of uncertainty with respect to these technologies. Overall, however, the expectation is that there will be a considerable increase in these value-added items.

Discussion of Panelists' Comments

The panelists' comments on this question are certainly worth noting. Clearly, definitional problems exist, particularly when looking at such areas as active suspensions. Federal regulations, as noted, could have a significant impact on at least several of the technologies in the forecast. Finally, the role of economics and the progress that has been made on existing vehicles were also noted. The high-tech or specialty-type car less sensitive to economic factors is expected to be the focus for many of the technologies.

Strategic Considerations

Based on the forecasts in the chassis area, it is evident that substantial percentage growth is forecast in a number of exciting technologies. One obviously important issue will be the cost of these systems, which will undoubtedly determine the extent of penetration across the vehicle fleet. Based on past experience, we would anticipate generally significant cost reductions, although in some cases the system complexity may be too great to permit substantial enough reductions to ensure long-term, broader application of the technologies. Regulatory standards could have an impact as well. Finally, there is no question that competitive forces or general market acceptance will have to be watched very closely in most of these areas.

TECH-25. What percent of U.S.-produced passenger cars will be equipped with four-wheel drive in the years 1990 and 1995?

	Percent Cars Equipped with Four-Wheel Drive	
Year	Median Response	Interquartile Range
1990	5%	5/10%
1995	15	10/20

Selected Edited Comments

A most ridiculous "fad" for other than off-road, recreation, and special-purpose vehicles.

Front-wheel drive will be the standard. That coupled with the anti-lock braking system will yield the handling and safety levels required by government regulation and consumer demand.

Discussion

Installation of four-wheel drive on U.S.-produced passenger cars is expected to increase to 5% in 1990 and 15% in 1995.

Comparison of Replies to Mkt-38

The Marketing panelists forecast a smaller percentage of four-wheel drive in passenger cars than did the Technology panelists with a forecast of 2.5% for 1990 and 3.5% for 1995.

Strategic Considerations

Although significant, the installation levels indicated are low in comparison to predictions made by non-technical enthusiasts in the general U.S. media but considerably higher than the percent forecast in the Marketing section of this Delphi.

There appears to be great uncertainty about the role of four-wheel drive. Of course the market will make the ultimate choice based on the consumers' cost-benefit analysis. The manufacturers should prepare accordingly in case the market develops.

Four-wheel drive could result in a significant value-added increment and create substantial new business opportunities.

TECH-26. We assume all cars will be equipped with seat belts. What percentage of U.S.-produced passenger cars will utilize the following additional safety features by 1990, 1995?

	Median Response		Interquartile Range	
Safety Features Utilized	1990	1995	1990	1995
Other Passive Restraint Systems	20%	35%	15/40%	20%/50%
High Technology Interior Crash Protection (friendly interiors)	10	25	10/15	20/35
Air Bags	5	10	5/10	10/25

Selected Edited Comments

This is basically a political forecast. I've assumed a decision based upon the merits of true technology as applied to specific types of cars.

As the discomfort of passive belts is more commonly known, air bags may grow in popularity. I don't really believe that passive belts are uncomfortable, but they may be so thought of by the American public.

Acceptance of air bags will increase as passive three-point-belts appear. Customers will prefer bags over the "webbing." Friendly interiors are an integral part of any restraint or air-bag system. As new interiors are designed, the "friendly" theme will be prevalent.

Air bags are too costly for not having to buckle up.

Consumer pressures will overturn federal regulation requiring passive restraints.

Manufacturer could never claim that a car has a "friendly" interior. Liability risk would be too great.

Passive belt restraint systems—only if the law requires it. I feel strongly that laws requiring mandatory use of current belts are necessary and reasonable.

Discussion

As indicated in the comments, safety-feature applications are dependent upon a mixture of technology and politics.

Strategic Considerations

Clearly this is one of the volatile and sensitive issues being addressed by the industry. The technology appears to be developing very rapidly and therefore a significantly different forecast might be envisioned in a relative short time. Both technical and political trends must be watched closely.

Recent developments and apparent commitments by manufacturers may skew results toward airbag technology.

It also seems likely that combinations of the technologies may be possible.

TECH-27. 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). Considering projected vehicle sizes, model mix configurations, engine types, and sizes for U.S.-produced passenger cars within the *lower technology/high volume* category, will the market penetration of the following accessories increase, decrease, or remain approximately the same relative to today, in the years 1990 and 1995?

	Compared to 1985 Percent Increase/Decrease (if any)			
	Median Response*		Interquartile Range*	
Accessories	1990	1995	1990	1995
Air Conditioning	10%	15%	3/10%	10/20%
Speed Control	10	10	5/20	8/25
Power Brakes	5	10	2/10	4/20
Power Steering	5	10	5/10	5/20
Power Windows	5	10	3/10	5/20
Power Door Locks	5	6	0/10	0/10
Power Seats	4	5	0/5	0/10

*All are increases.

Selected Edited Comments

By 1995 speed control can go up to 50% as engines and transmissions go additionally to electronic control.

Discussion

Forecasts call for continuing growth in the market penetration of major accessories in the lower technology/high-volume category of the U.S. passenger car market.

Air conditioning and speed control are expected to experience the greatest increase in 1990 with air conditioning, power brakes, power steering, power windows, and speed control with a greater growth rate by 1995. The interquartile range is relatively broad on all power features, indicating a significant level of uncertainty. This may be due in part to the difficulty in categorizing vehicles in the simplified two-segment groups that we have suggested.

Comparison of Vehicle Manufacturer and Supplier Panelists

In general the vehicle manufacturers were more optimistic than the supplier panelists in the percent increase of the accessories listed. Manufacturers' 1990 forecasts for power steering, windows, seats, and door locks were on an average 5% more than the increase suggested by the suppliers. The same is true for 1995, except for power brakes and power steering, where the responses were identical.

Strategic Considerations

It is evident from the data that a considerable increase in various power accessories is expected in the generally lower technology/higher volume vehicles. Because of the size of this overall market, the impact on the various power accessories would appear to be substantial in the years ahead. Of course, one must closely watch the cost/benefit tradeoffs that customers in these market segments employ in their buying decisions. Changes and trends of this type reinforce the importance of staying close to the market.

TECH-28. *The following is a two-part question.*

TECH-28A. What significant changes in tires will be introduced in the next ten years?

Performance and Design Changes: *100% Total Respondents*	Percent Within Group Responses
Improved traction	18%
Improved cornering, handling, and ride control	16
Lower rolling resistance	11
Lifetime tires (100,000-mile life)	11
Lower aspect ratio	11
Wider tires	8
Improved uniformity	5
More aggressive all-weather treads	5
Other comments:	15

Increased wear and bruise resistance.
More high-performance tires.
Lower life of tires resulting from improved traction.
Low-profile tires.

Construction Changes: *71% Total 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.

Elimination of the Spare: *16% Total Respondents*	
No spare	67%
Run flat	33

Others:

Non-pneumatic spare
Speed-rated tires that also offer excellent economy and traction in rain and snow.
A "throw-away" spare.
Factory warranty rather than tire company.

Representative Responses

"Tire within tire" flat protection. Trend on sporty cars toward 50 and 60 series will continue.

Continued evolution to improve ride, handling and traction, and some introduction of run flat tires.

Larger diameter wheel and tires for appearance reasons and ride comfort.

Lower drag, lower aspect ratio, better wet vs. dry traction, less white side walls.

Regain the wear characteristic lost in the move to more aggressive tread designs.

Some acknowledgment of a "V+" rating for speeds in excess of 130 mph.

Calibration optimization for all-wheel drive. Rolling loss reduction with wide profiles.

Discussion

The results in Tech-28A are fairly clear without a detailed explanation. Most of the changes expected reflect continued incremental improvements. The major exception is the expectation on run-flat tires. About the same percentage—8%—as in the past forecast the elimination of the spare tire.

Strategic Considerations

It is clear that there is reasonable optimism for some change in this important tire-related area and technological developments must be watched closely. A number of systems have been proposed that with breakthrough or even steady improvement could result in relatively fast, high-volume commercialization in a relatively short period. Then the expectations for these factors could rise substantially.

TECH-28B. What is your expectation for the future of spare tires in U.S.-produced passenger cars in the model year 1995?

Spare Tire Expectation for 1995	Percent of Respondents
Elimination of spare	45%
Introduction of tires which will allow the reduction/elimination of spares*	31
Continuation/increase in usage compact spares	18
Reduced/limited usage of conventional spares	16
Retained as customer option only	11

*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: 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%).

MEDIAN FORECAST FROM THREE DELPHI SURVEYS
1990 CARS WITH AND WITHOUT SPARE TIRES

	Forecast for 1990 at the Time of the Survey		
U.S.-Produced Cars with:	1979 Delphi I	1981 Delphi II	1983 Delphi III
No Spare	50%	26%	5%
Standard Spare	0	11	15
Mini-Spare	50	63	80

Representative Responses

"Psychological attitude" of consumer will require supply of spare tires except for "run flat."

Due to improvements in puncture resistance, sealing, and the incorporation of run-flat designs, the spare may be obsolete. People (at least a small percentage), however, will demand them.

Technology will be there. It will require tremendous education to make people accept them.

Mini-spare usage will increase; conventional spare will be much reduced; no-spare will be acceptable to 20% of the market.

A high percentage of small emergency spares.

Continue compact spares in the majority of cars with possible non-pneumatic tires in some use. No elimination of the spare—pity!
Spare deleted in lieu of run-flat standard tire, probably first in luxury models.
Will essentially disappear except as a customer-ordered after-sale item.
Either a very low cost "throw away" or development of a "limp home" regular tire.
Generally would expect "compact" spares to continue to dominate.
Mini-spare to continue although in certain instances a full-sized spare may be used as a marketing tactic.
Non-pneumatic units and radial mini-spares will be predominate where spares remain.
There will still be one—but a marginal mini-tire compared to today's. Full-size spare no longer even an option.
Wider (universal) use of temporary spares.

Discussion

The most important finding is the resurgence of interest in the elimination of the spare tire. Approximately one-half of the panelists forecast the direct elimination of the spare, with about one-third indicating the introduction of new tire designs and technologies that will allow the reduction or elimination of the spare. Only 27% of the panelists expect continued limited use of spares with a substantial portion of that group forecasting the retention of the spare as a customer option only.

Trends from Previous Delphi Surveys

In previous Delphi surveys, panelists were asked to forecast the percentage of U.S.-produced cars that will have mini-spares, standard spares, or no spares. Although the questions are not precisely comparable, the trend table of previous Delphi forecasts, when compared with Delphi IV forecasts, clearly illustrates the resurgence of interest in the elimination of the standard spare tire.

Strategic Considerations

The responses to this question have varied considerably over the years. In the early 1980s, optimism for spare tire elimination soared and then faded dramatically in Delphi III. Perhaps solid technical achievements are responsible for the present forecast. Trends should be monitored closely because the implications on both the tire industry and the vehicle-design process are significant.

TECH-29. Name new vehicle interior developments (instrumentation, seating, trim, etc.) that you expect to see on U.S.-produced passenger cars within the next ten years.

The following new vehicle interior developments are rank ordered according to the total number of panelists' responses. Percentages presented are a result of "within-group" analysis.

Instrumentation: *77% Total Respondents*	Percent Within Group Responses
Proliferation of CRT displays. CRTs will most likely feature navigation, diagnostic, and guidance systems	48%
More electronic instrumentation in next ten years	37
Analog instrumentation will be more standard	4
Possible use of heads-up displays	11

Seats: *54% Total Respondents*	
Seats will be thinner with increased comfort	42%
Luxury perception of the seats will be increased	16
Seat adjustment will be programmed (memory seats)	16
Other	26

- Adjustable rear seats
- Air bladder cushions
- Foamed in-place seating
- Improved rear-foot clearance
- Maintenance-free seat coverings
- More bucket seats
- Seats with molded fabric/cushion material which incorporate thinner, stronger sections

Friendly Designs: *6% Total Respondents*

Friendly interiors through the use of softer composites.

One suggestion for use of flame-retardant materials inside car.

Modular Interior: *8% Total Respondents*

More convertibility between passenger-carrying provisions and cargo-carrying provisions

Doors and Trim: *8% Total Respondents*

Doors and trim will be fully molded

Ergonomics: *6% Total Respondents*

Redistribution of controls for greater convenience
Use of control pods which move with steering wheel tilt

Representative Responses

Back to analog/more readable and less confusing instruments. More comfortable seats with adjustment features.
Speed control that adjusts to the car ahead.
Back lighted instrument clusters (a la aircraft), especially those located off the dashboard such as mirror, window, and door locks.
Computer terminals as part of instrument package.
Cloth–covered instrument panels, two–color vinyl; overhead consoles; more instrumentation in doors.
Convenient storage of small articles, built-in telephones.
More driver aids and entertainment systems. Some directional aids.
Power memory seats, steering, pedal and mirror adjustments.
Passive interior.
CRT displays, additional information displays, control panels for car systems (e.g., suspension, steering).
Improved seating materials with good appearance but less drag.
Increased attention to manual seat adjustability.
Instrument panel made of laminated plastic—one piece. Touch screen as on supermarket cash registers now. Instrument panel design driven electronically.
Surface appearance and "feel" among instrument panel pad, molded door trim panels, console and other molded components.

Discussion

The responses are clustered according to groups of: instrumentation, seats, general interior design, ergonomics, modularity, and doors and trim. Questions of this type generally prompt panelists to suggest what they speculate might be available during the forecast period. The greatest focus of the panelists was in instrumentation, with proliferation of advanced types of displays, including CRTs and, in general, more electronic controls in seats, with emphasis on more compact seating and more comfortable and programmable-adjustment seats. Also, friendly interior design received substantial support from the panelists.

Strategic Considerations

Clearly there are a wide range of developments expected in the interior of vehicles in the next ten-year period. One is cautioned not to infer penetration levels from the suggestions of the panelists. The forecast is only that these technologies will be used in the next ten years.

Market forces and the shift to modular construction could have a major influence on trends. A systems approach to interior design may be critical to meeting both cost targets and customer requirements.

TECH-30. Manufacturers are striving for lower cost, more compact, more efficient and comfortable seat design. What major changes in seat design and construction do you foresee will be utilized to achieve this objective?

Changes in Seat Design: *55% Total Respondents*

All of the panelists within this group addressed the issue of improved comfort.

Within this group 28% suggested the need for contoured seats with better lumbar and lateral support. Thirty-one percent (31%) felt that increased comfort will be achieved through more seat adjustments. Fifty-six percent (56%) of the panelists within the group specified that the seat adjustments would be pneumatic, and some felt that the adjustments would be equipped with a memory mode. Another common response was that seats will be lighter weight and have thinner profiles.

Changes in Seat Construction: *45% Total Respondents*

The majority of comments on the future *construction of seats* represent the idea of simplifying the construction process through the integration of the frame, foam, and covering material.

Within this group, 75% forecast that mold-in-place construction will replace cut and sew. Nineteen percent expect that future seats will be made of composites and an additional 6% expect future seat designs to incorporate central spine construction, linked adjustments, and variable density foam.

Representative Responses

Seat ventilation and heating/seat fixed and adjustable steering column, etc.

Greater penetration of sport seating for specialty models. Further development of seat-belt systems anchored to seat structure.

Improved back support and adjustment of back of seat in front.

Modular seats, *hopefully* more durable seats, more shape or profile control.

More available adjustments, possibly seats that are fluid filled and conform to the driver, as in ski boots, helmets, etc.

No major changes in basic design, but more power seats, memory seats, more adjustable aspects of parts of seat (lumbar support)—on balance, more complex seats.

Stronger but simpler construction, more latitude in control.

Tubular steel designs and some one-piece molded types (if breathability is solved). Power seats.

Strategic Considerations

The range of thinking is very broad and indicates that many technical developments are being actively explored. We should expect a variety of different designs that will address the functional needs of the customer. Each comment should be considered carefully.

Great pressure on interior space will undoubtedly lead to innovation that will reduce the volume occupied by seats. Another key factor in seating will be the emergence of modular seat systems. Since the customer has a rather intimate relationship with the seat, market forces must be tracked carefully.

TECH-31. What percentage of passenger cars and light-duty trucks manufactured in the U.S. in 1990 and 1995 and using a piston internal-combustion engine will be equipped with engines of 3, 4, 6, and 8 cylinders?

		Passenger Cars			
		Median Response		Interquartile Range	
Engines with:	Est. 1985	1990	1995	1990	1995
3 Cylinders	0%	0%	2%	0/2%	0/5%
4 Cylinders	47	50	50	45/50	45/55
6 Cylinders	26	30	35	30/33	30/40
8 Cylinders	27	20	13	17/21	10/17
			Light-Duty Trucks		
3 Cylinders	0	0	0	0	0
4 Cylinders	18	45	45	40/50	40/55
6 Cylinders	37	35	35	35/40	30/40
8 Cylinders	45	20	20	20/35	10/20

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
NUMBER OF CYLINDERS IN CARS PRODUCED IN THE U.S.
IN THE 1990 MODEL YEAR

Number of Cylinders	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Two	N.A.	2%	0%	N.A.
Three	N.A.	10	2	0
Four	70	60	53	50
Five	N.A.	5	0	N.A.
Six	25	20	35	30
Eight	5	3	10	20

Selected Edited Comments

Future 6- and 8-cylinder engines will have smaller displacements. Many 4-cylinder engines will be replaced by similar displacement 6-cylinder engines for improved performance.

Many customers dislike low torque 4-cylinder engines since transmission shifts constantly and is noisy. Big V-8s do not have this problem.

Most new engine capacity being added is for 6-cylinder engines.

Lighter weight vehicles will cut need for V-8s. New people coming into light-duty trucks will want fuel economy similar to that of their passenger cars.

There will be a tendency to replace both 4- and 8-cylinder engines with 6 cylinders.

Three-cylinder two-stroke engines show promise.

Improved performance of four-cylinder will increase popularity.

Recent developments in four-cylinder engines in terms of low friction, lower inertia components, and multi-valve with overhead cams and turbochargers (mostly Japanese engines) are leading to very smooth running, high-powered, lightweight engines. From a vehicle design point of view, six-cylinder engines are positioned as up-level engines. Therefore, V-8s are likely to die out if not by 1995, certainly by the year 2000.

Discussion

The general trend toward smaller engines with fewer cylinders in both passenger cars and light trucks is forecast to continue through 1995. A continued reduction in the percentage of V-8 engines is expected, although at a significantly slower rate than predicted in previous Delphis. In-line 4-cylinder and V-6 engines are expected to predominate in the market, occupying 80% of the market for passenger cars and 70% light trucks in 1990. Three-cylinder engines are expected to enter the passenger car market around 1995 with a 2% share. The interquartile range for passenger cars is very close, indicating a very good consensus among the panelists. The interquartile range for 4-cylinder and 8-cylinder light trucks is somewhat broader, indicating some uncertainty as to the ratio of application of these two engine configurations.

Discussion of Panelists' Comments

The panelists' comments elucidate many of the underlying factors contributing to the trend toward smaller engines. They also describe adjustments being made to accommodate the persistence of the V-8 engine in the marketplace.

Comparison of Vehicle Manufacturer and Supplier Panelists

The OEM and supplier panelists were in agreement regarding the median distribution of the number of cylinders in piston internal-combustion engines through 1995. The interquartile range for these two groups also reveals a very good consensus.

Trend from Previous Delphi Surveys

As illustrated in Figure T-6 below, there have been some significant alterations in forecasts for engine mixes since the first Delphi in 1979. The increase in projections for 8-cylinder engines at the expense of 4-cylinder engines and other smaller engines is the most obvious observation.

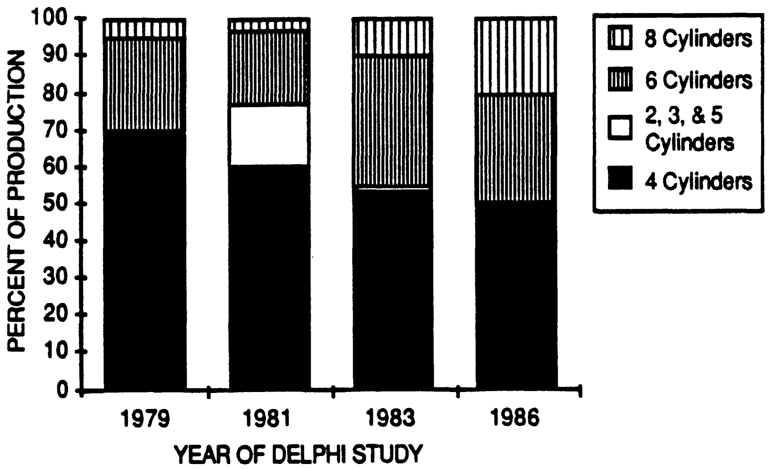

FIGURE T-6. Number of Cylinders in 1990 Cars (Percent of U.S.-Produced Passenger Cars and Light Trucks Using 2, 3, 4, 5, 6, and 8 Cylinders)

In the 1979 forecast it was projected that 4-cylinder engines would be used in 70% of U.S.-produced passenger cars. This estimate dropped to 60% in the 1981 Delphi II and continued to drop through Delphi III, gradually leveling out at the current Delphi IV estimate of 50%. In the Delphi III assessment it was thought that the decline in 4-cylinder engines reflected an expected gain for 2- and 3-cylinder configurations. In 1981 it was thought that these engines would account for 12% of the U.S. car market. In this survey, the V-6 and V-8 engines are expected to equally divide the U.S. passenger car market with 4-cylinder engines. Similar trend data is not available for light-duty trucks.

Strategic Considerations

Consistent with other parts of the Delphi forecast, such as future vehicle weight and material usage, there is considerable moderation in the panelist's expectations for the future. The V-8 is not expected to die, nor is the 4-cylinder engine expected to overwhelmingly dominate. Although the pressures of CAFE still favor small engines, the market appears to demand a balanced collection of power plants.

TECH-32. On a percentage basis, indicate the mix of spark-ignited engine displacements you expect in U.S.-produced passenger cars made in 1990 and 1995.

	Median Response		Interquartile Range	
Displacement in Liters	1990	1995	1990	1995
5.1+	6%	2%	2/10%	0/5%
4.1-5.0	11	10	10/15	5/10
3.1-4.0	27	26	20/30	15/30
2.1-3.0	33	36	25/40	25/45
1.5-2.0	20	21	10/25	13/26
Below 1.5	3	5	0/5	0/10
TOTAL	100%	100%		

MEDIAN FORECASTS FROM THREE DELPHI SURVEYS
1990 ENGINE DISPLACEMENTS
U.S.-PRODUCED PASSENGER CARS

Displacement in Liters	1981 Delphi II	1983 Delphi III	1986 Delphi IV
5.0+	0%	5%	6%
3.0-5.0	15	30	38
1.5-3.0	66	55	53
Below 1.5	19	10	3
TOTAL	100%	100%	100%

Selected Edited Comments

Higher specific output will improve absolute power and reduce displacement to maintain economy while improving power.

Discussion

The decline of engine size as measured by displacement appears to be leveling off. Panelists estimate that 53% of the engines will be in the 1.5-3.0 liter displacement by 1990. This percentage is expected to increase slightly to 57% by 1995. Mid-size engines in the 3.0-5.0 liter displacement range are forecast to occupy 38% of the U.S.-produced passenger car market by 1990 and to remain at a relatively stable 36% through 1995. Larger engines of above 5.0 liters are expected to be at 5% in 1990 and drop to 2% of spark-ignited engines by 1995. Smaller engines below 1.5 liters are forecast to increase from an expected 3% in 1990 to 5% by 1995. The interquartile ranges reveal considerable uncertainty regarding the median forecasts, particularly at the high and low end of the displacement scale.

The major finding here is the slowing of the trend to smaller engines. This was to be expected for two reasons. First, fuel prices (adjusted for inflation) are near their historical lows, and second, improved engine designs allow larger engines to achieve fuel efficiency levels that could previously be obtained only by decreasing engine displacement.

Discussion of Panelists' Comments

"Higher specific output will improve absolute power and reduce displacement to maintain economy while improving power." This could be a powerful force in enhancing the role of smaller engines.

Comparison of Vehicle Manufacturer and Supplier Panelists

The only significant disagreement between the OEM and supplier panelists is on the 1990 forecast for 1.5–2.0 displacement engines, where the OEM panelists expect only 15% (interquartile range of 10/25) of the mix. Similarly in the 1990 forecast for engines below 1.5 liters displacement, the supplier panelists estimate only 1% (interquartile range of 0/5) of the mix. However, it should be noted that the interquartile ranges for both of these forecasts are broad and should be treated accordingly.

Trend from Previous Delphi Surveys

As is shown in the comparison table, panelists have considerably expanded their expectations for the larger-displacement engine groupings for 1990 and, in turn, diminished their expectations for the lower-displacement engines. Based on current market trends, earlier predictions of a wholesale downsizing of engines have diminished.

Strategic Considerations

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 with a significant 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 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 key.

TECH-33. What percentage of current production U.S. engines will be fundamentally redesigned by 1995?

	Percent U.S. Engines Redesigned by 1995	
	Median Response	Interquartile Range
4-Cylinder Engine	60%	50/80%
V-6 Engine	50	45/70
V-8 Engine	40	10/60

Selected Edited Comments

V-8s will be replaced by V-6 and V-4s—not redesigned as V-8s.

All engines in production in 1986 will have a redesign for 1995.

All engines will have major redesigns by 1995 with the exception of four-valve OHC engines now coming out.

Almost 100% of engines will have new cylinder heads.

New heads everywhere for performance and packaging.

Engine life cycles will decrease substantially over the next ten years.

I feel that almost every current engine will have been replaced by a new design by 1995.

Most current engines are already getting dated (5+ years). The same question for 1990 would be interesting.

Practically all engines produced today will be redesigned.

Discussion

The panelists expect a substantial percentage of existing U.S.-production engines will be fundamentally redesigned by 1995. However, the rather broad interquartile ranges, particularly with respect to V-8s, indicates substantial uncertainty as to what actual percentage of engines may experience redesign.

Discussion of Panelists' Comments

A majority of the comments suggest that the percentage of current U.S.-production engines to experience fundamental redesign by 1995 may exceed the median response of the combined technology panels.

Comparison of Vehicle Manufacturer and Supplier Panelists

While the vehicle manufacturer and supplier panelists were in agreement on the percent of V-6 engines that will be fundamentally redesigned by 1995, there was some disagreement on 4-cylinder and V-8 engines. For 4-cylinder engines, the supplier panelists forecast 70% to be fundamentally redesigned, versus 60% for OEM. Regarding the V-8, the manufacturers forecast 50% versus a supplier forecast of 30%.

Strategic Considerations

Comments are strongly supportive of almost complete redesign of existing engines, although the numerical forecast data do not bear this out. Nevertheless, the forecast magnitude of redesign represents an enormous and very expensive undertaking. It is possible that competitive pressures from worldwide peer manufacturers will force a higher level of redesign than anticipated. New engines may be required to even get on the "playing field" where the long-range competitive battles will be fought. Market forces are critical.

New engines will clearly compete fiercely for investment dollars in the next few years and could result in the deferral of investment in other areas of the vehicle.

All existing engines are being improved significantly. They are being "upteched" and made far more precisely. Key components such as pistons, cams, etc., are rapidly being redesigned and sourced with suppliers that can meet far more demanding product and quality requirements.

TECH-34. What approximate percentage of existing engine tooling will be usable for new-generation engines?

	Median Response	Interquartile Range
Percentage Engine Tooling Usable for New Engines	30%	25/45%

Selected Edited Comments

Basic-block machining will be spared—multivalve heads, smaller displacement V-8 and V-6 engine will require new equipment.

Fixed plants will be gone, flex plants will be the norm in 1995.

Flexible machining systems will predominate by 1995. High-speed machining will replace current technology.

Discussion

The panelists forecast that only 30% of existing engine tooling will be usable for new-generation engines. The upper interquartile level is significantly higher.

Comparison of Vehicle Manufacturer and Supplier Panelists

The two groups of panelists forecast almost identical medians. However, in this particular question the interquartile ranges are worthy of note: OEM=30/40 and Suppliers=25/50.

Strategic Considerations

Flexible machining systems, if prevalent, indicate fundamental changes in manufacturing design paralleling new engine designs. This question has significant implications for capital budgets.

TECH-35. What percentage of the vehicles manufactured in the U.S. in the listed years will be equipped with diesel engines?

	Percent Equipped with Diesel Engines			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Passenger Cars	2%	3%	1/2%	2/5%
Light Trucks (1-14,000 GVW)	10	15	10/10	10/15
Medium Trucks (14,000-26,000 GVW)	40	50	30/50	40/60

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
DIESEL ENGINES IN DOMESTIC VEHICLES IN 1990

U.S.-Produced with Diesel Engines	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Passenger Cars	25%	20%	10%	2%
Light Trucks (1-14,000 GVW)	N.A.	25	20	10
Medium Trucks (14,000-26,000 GVW)	N.A.	N.A.	50	40

Selected Edited Comments

Emission laws will dictate usage in trucks.

Depends upon fuel prices and relaxation of particulate emission standards.

Emission laws are too tough with present poor quality U.S. passenger car fuels.

In absence of tax advantages, only a few diesels will be sold. By 1995 some semi-adiabatic direct injection (DI) diesels will draw buyers.

Direct injection (DI)/adiabatics will definitely become more prominent.

Diesel usage is still decreasing. Only a complete reversal in fuel availability will reverse the trend. Diesels don't make much economic sense when diesel fuel is approximately 30% more expensive than gasoline.

Highly dependent on fuel prices.

Not much interest for passenger cars unless fuel prices increase sharply.

Discussion

Diesel engine use in passenger cars is expected to rise from an estimated 1986 passenger car total of less than 0.5% to 2% in 1990 and to 3% in 1995. Diesel usage is forecast at 10% for 1990 and 15% in 1995 for light-duty trucks and 40% and 50%, respectively, for medium-weight trucks. The interquartile ranges for passenger cars and light trucks are very tight, indicating an equally good consensus. The interquartile range for medium trucks is somewhat broader, indicating a degree of uncertainty regarding the increasing application of diesel engines in this weight class.

Discussion of Panelists' Comments

The comments cover many factors affecting the relative utilization of diesel engines. Comments addressing the effect of fuel prices on diesel use deserve serious consideration for strategic planning in the event of a future fuel/gasoline crisis.

Comparison of Vehicle Manufacturer and Supplier Panelists

The vehicle manufacturers forecast that 2% of U.S.-produced passenger cars will be equipped with diesel engines in 1995; the suppliers forecast 4%. Otherwise their responses are identical.

Trend from Previous Delphi Surveys

Forecasts from four Delphi studies clearly indicate a very significant decline in expectations for diesel engines in U.S.-produced passenger cars. Although a trend of increasing decline is evident for light trucks, it is not a significant factor for medium trucks, where diesels are still expected to have a prominent role.

Strategic Considerations

Expectations for the diesel in passenger cars continue to fade at least in part because of significant improvements in gasoline engines. Of course, another major energy crisis could alter these expectations but not to the extent of the 1970s, because of important gains in gasoline engine fuel economy, which substantially decreases the savings at the margin. See also Tech-1 and Tech-2.

TECH-36. Advanced engine types have been considered for many years in U.S. light-duty vehicles. When do you expect the following engines will attain commercial production quantities (30,000 units) in the U.S.?

Engine Types	Year of Commercial Production: Median Response	Year of Commercial Production: Interquartile Range
Gas Turbine	2000	2000/2000
Open Chamber (D.I.) Diesel	1993	1992/1995
Stratified-Charged Spark-Ignited	1995	1992/1995
Rotary Combustion or Wankel	2000	1995/2000
Low-Heat Rejection Engines	1998	1995/2000

Selected Edited Comments

Wankel assumes that Mazda/Ford set up joint-engine production in the U.S.; stratified charge—Honda plant in Ohio.

Ceramics could breath new life in Wankel efficiency. Low-heat rejection implies both adiabatic and turbo compound or other use of exhaust temperature, thus complexity precludes economic use in light-duty applications. Low-heat rejection engines—heavy duty only.

Gas turbine dependent upon ceramics technology development.

Low-heat rejection engines will be introduced on an incremental basis in H.D. diesels beginning in 1990 or before—technology will trickle down to automotive.

More "packaged" engines will emerge—these are engine/transmission units that can be put in very compact locations (i.e., under rear seats) to open up more passenger/luggage areas in other parts of the car.

Rotary combustion or Wankel in 2000 or later.

The D.I. diesel will be accepted only if it can meet emissions standards. At the current HC and particulate levels, this is questionable. At some of the projected levels, it may be impossible. The stratified-charge spark-ignited engine takes many forms. Direct-injected engines offer fuel economy and fuel tolerance advantages which can only justify the engine's higher cost if fuel prices rise dramatically. D.I. diesel: only if particulate standards relax. Rotary combustion or Wankel is not in the foreseeable future.

Two-cycle engines by 1991-1992.

Gas turbine not meaningful with known characteristics.

Discussion

Expectations are not high for advanced engine designs as an alternative to current spark-ignited and diesel engine designs. The open chamber diesel is forecast by 1993 and the direct-injection, stratified-charge, spark-ignited engine is predicted by 1995. The other engine types (gas turbine, Wankel, and low-heat rejection) are not expected until the next century, if then. The interquartile ranges are close, indicating a good agreement among the panelists regarding the year of commercial introduction for these engine types.

Discussion of Panelists' Comments

The comments provide some interesting insights and perspectives on factors that could affect the date of commercial introduction of some of these engines.

Comparison of Vehicle Manufacturer and Supplier Panelists

The two groups are in general agreement with the one notable exception of the rotary combustion or Wankel engine, where the median forecast of the OEM panelists was 1995.

Comparison from Previous Delphi Surveys

Current Delphi projections for the gas turbine and Wankel engines are in accord with the forecast of the Delphi III. Delphi III forecasts for the commercial production of the open chamber (DI) diesel and stratified-charge engine are five years earlier than current Delphi forecasts.

Strategic Considerations

The future role of these engines is uncertain. Developments must be watched closely and of course the present type of engine is presenting a challenging, moving target to all competitors. Significant technical breakthroughs or a different-than-expected energy future could alter expectations.

We question the panelists' perception of "light-duty" in this question. Some of the engines are, perhaps, more likely in various heavy-duty applications.

TECH-36A. What percent of U.S.-produced passenger cars and light-duty vehicles will incorporate the following advanced engine types in the years 1995 and 2000?

	Percent U.S.-Produced Passenger Cars and Light-Duty Vehicles			
	Median Response		Interquartile Range	
Engine Type	1990	1995	1990	1995
Open Chamber (D.I.) Diesel	2%	5%	1/5%	2/10%
Stratified Charge Spark-Ignited	2	5	0/5	2/10
Low-Heat Rejection Engine	1	2	0/2	1/10
Rotary Combustion or Wankel	0	1	0/2	0/3
Gas Turbine	0	0	0/0	0/2

Selected Edited Comments

Low-heat rejection and D.I. diesels will be tied together.

D.I. diesel technology will probably arrive, but U.S. light-duty market re-acceptance of any diesel will be slow. Multivalves open fertile possibilities.

Discussion

Expectations for various alternative power plants presently not used in automotive applications are very modest. However, as noted in the prior question, even small numbers can be significant. Particular optimism was expressed for both open chamber direct-injected diesel and stratified-charge, spark-ignited engines. Both low heat rejection engines and the rotary combustion or Wankel received less support, and the gas turbine is essentially not a viable alternative prior to 1995. The interquartile ranges expressed were quite broad, indicating reasonable uncertainty, but reinforce the modest level of expectations seen in the median.

Discussion of Panelists' Comments

The two comments pertinent to direct injection diesels are significant. Also, we would certainly reinforce the idea that the direct-injection diesel may struggle in the light-duty market.

Strategic Considerations

The U.S. industry is continuing to look at various alternative engines. All of the engines mentioned have been considered for some time for various applications in both light- and heavy-duty vehicles. While the expectations are modest, even these are significant and suggest that some of the major technical problems will have been resolved on these engines. Obviously the ultimate acceptance will depend on further developments and very importantly, basic economics. In addition, trends in fuel pricing and availability and overall customer acceptance are critical factors. There is no question that any prudent power plant manufacturer must carefully watch technology both here in the United States and in the world. Some technologies such as the direct-injection, stratified-charge diesel engine may be more supportable in areas such as Europe and Japan.

TECH-36B. What percentage of U.S.-produced passenger cars will utilize two-cycle gasoline engines in the years 1995 and 2000?

	Percent U.S.-Produced Passenger Vehicles			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Two-cycle engines	1%	3%	0/2%	1/10%

Selected Edited Comments

Many problems: cost of fuel injection, oil consumption/lubrication, emissions, etc.

Australian development of two-cycle looks promising—many Detroit OEMs investigating at advanced stage.

Depends on whether the new two-stroke concepts can meet emissions standards.

I expect some surprising developments within ten years. New developments in fuel and air delivery may represent real breakthroughs.

People must accept the performance. How long did it take us to get back to four-cycle engines?

Power-to-weight, size is strong inducement; long-term testing of durability, emissions is needed.

Very dependent on success of current research and development work going on, such as Orbital.

Solutions to hydrocarbon emission control with good fuel economy have not been demonstrated as satisfactory for vehicle engines. Noise problems also have to be solved from the product quality point of view.

Discussion

This was a third-round question prompted by several comments in the first two rounds regarding powertrain issues. It is evident that there is only modest but still some support for the potential role of the two-cycle engine in 1990 through 1995. The data actually are far more significant than the small numbers would indicate, because if success is achieved during this time frame the impact on future engine design could be very substantial. The interquartile range is very small for 1990, expands dramatically in 1995, and is a significant measure of the uncertainty.

Discussion of Panelists' Comments

The many comments address some of the primary problems that a two-cycle engine faces in an automotive application. Several noted the Orbital engine project from Australia. There are, however, other activities independent of this particular project.

Strategic Considerations

Development of a reliable automotive two-stroke cycle engine could have a profound impact on powertrains in the years ahead. This engine promises to be much smaller, less expensive, with potentially almost twice the power density per cubic inch of displacement of current four-stroke designs. The problems are evident. However, based on technological developments, one cannot dismiss this engine out of hand. Developments, particularly in the area of fuel injection, would permit a reasonably homogeneous mixture early in the compression stroke and may permit efficient and reasonably clean combustion. This development must be watched very closely by all in the industry. It is typical of the ever-changing nature of the automotive industry that this technology should appear. In a sense, it may represent the harvesting of a host of technologies that have been applied in other areas, such as the experimental work on the direct-injection, stratified-charge, four-cycle engine.

TECH-36C. What critical problems remain to be solved before the commercial introduction (30,000+ units) of two-cycle gasoline engines in U.S.-produced passenger cars? Please comment.

The *principal* critical problems that remain to be solved before the commercial introduction of two-cycle gasoline engines in U.S.-produced passenger cars are:

Direct cylinder fuel injection
Emissions
Mixture of oil and gas

In terms of percent of total responses, the following may be considered *secondary* two-cycle engine problems that remain to be solved:

Noise
Smoke
High engine temperature
Fuel consumption
High rpms

Selected Edited Comments

Two-cycle engines yield high power-to-weight ratio, but emissions regulations could be a problem.

There is no one problem—simple reaching a "system" solution which will yield appropriate emissions levels—a fine balance of electronics, injector performance port timing and purge air technology (big job).

Mixing oil and gas will never fly.

Discussion

The response to this question can be stated rather simply. Obviously, emission regulations create a critical barrier that any potential alternative engine must hurdle before commercial application. In addition, a direct cylinder fuel-injection system required to prepare the mixture following port closing and prior to ignition faces a very significant challenge. There is a very short period of time available to achieve reasonable mixture homogeneity at high engine speeds. The comment related to a systems approach to this technology is extremely pertinent. Developments should be carefully watched, particularly since some research engines have apparently demonstrated the ability to meet emission standards.

TECH-37. What percentage of U.S.-produced passenger car engines will incorporate the following technical features by the year 1990 and 1995?

Technical Features	Median Response 1990	Median Response 1995	Interquartile Range 1990	Interquartile Range 1995
Fast-Burn Combustion Chamber	50%	75%	40/60%	55/80%
Knock-Limiting Devices	50	70	40/50	55/75
Roller Lifters	40	50	30/50	40/60
Direct Fire (Distributorless)	25	50	20/30	40/65
Balance Shaft (% in 4-Cylinder Engines)	20	25	10/25	15/35
Four-Valve Combustion Chambers	10	20	5/10	15/30
Lean-Burn Technology (General)	10	20	5/15	15/30
Powdered Metal Cam and Gears	10	20	5/10	10/25
Balance Shaft (% in 6-Cylinder Engines)	5	10	0/10	5/10
Hollow Camshaft	5	15	5/10	10/20
Three-Valve Combustion Chambers	5	10	5/5	10/15
Variable Valve Timing	5	10	2/5	10/15
Twin Spark Plugs per Cylinder	4	5	1/5	5/10
Axial-Stratified Charge	0	2	0/0	0/5
Plasma (or Other Advanced) Ignition	0	2	0/2	0/5
Other Innovations:				
Reduced Maintenance Requirements	30	40	30/80	40/100
Electronic Fuel Management	30	40	20/80	30/100
Superchargers	10	20	9/10	15/22
Two-Cycle Engine Technology	0*	10*		
Intercoolers for Turbocharger	5*	10*		

*Denotes a single response.

Selected Edited Comments

I expect balance shaft popularity in four-cylinder engines to fade as advanced material applications reduce reciprocating weight and second-order disturbances.

Electronic knock sensing, mostly on luxury/performance/boosted models in 1990. Will become typical everywhere by 1995.

"U.S.-produced" can be a fuzzy term, with parts outsourcing (the norm for lower volume exotics) and U.S. "dressing."

Lean burn depends on NOx level required—unlikely at 0.4 NOx.

EFI/CFI will sweep carburetors off the market.

Elements of axial stratified-charge technology are already in use, i.e., Ford HSC and Chevy 4.3 liter V-6 with very high swirl tangential ports.

More smaller turbochargers (versus large turbos) for better off-idle response.

Use of roller lifters will decrease as pushrod engines are replaced with OHC designs. Balance shafts on six-cylinder engines are only likely to be used on 90° V-6 engines.

More "packaged" powertrains will emerge. These will allow more compact installations and more passenger space.

Discussion

A number of new and emerging technologies were surveyed as to their incorporation in U.S.-produced passenger cars by 1990 and 1995. The leading technological features expected by the panelists are: fast-burn combustion chambers, knock-limiting devices, and roller lifters. These features are expected to be incorporated in 40% to 50% of passenger cars by 1990 and 50% to 75% by 1995. Additional features specified under "Others" also deserve serious attention.

Discussion of Panelists' Comments

The comments presented here provide insight into the technological and market forces and trends affecting some of the technical features surveyed.

Comparison of Vehicle Manufacturer and Supplier Panelists

The vehicle manufacturers and suppliers evidence a remarkable consensus on the percentage of U.S.-produced passenger cars that will incorporate the technical features listed. Few significant differences exist. One is in the projection for balance shafts. The OEM panelists forecast 10% for four-cylinder engines in 1990 and 5% for V-6s in 1995. A possible explanation for this reduced percentage is offered in the panelists' comments referring to balance shafts (see "Selected Edited Comments").

The vehicle manufacturers also forecast a lower percentage for variable valve timing, projecting 2% in 1990. Suppliers forecast two spark plugs per cylinder at 2% in 1990; the OEM forecast 5%.

Comparison of Trends with Previous Delphi Surveys

Delphi III panelists also listed knock-limiting devices as a major technical feature to see application by 1992. Those features that were surveyed in both Delphi III and Delphi IV and are compared in the following table.

	Delphi III 1992 Forecast	Delphi IV 1990 Forecast
Knock-limiting devices	50%	50%
Hollow camshaft	20	5
Powder metal cam and gears	20	10
Direct-fire ignition	20	25
More 2 valves/cylinders	10	15
Variable valve timing	5	5
Balance shaft in 4 cylinder	15	20

Strategic Considerations

This question is extremely broad and covers a variety of new technology. The magnitude of a number of the forecasts suggests that substantial value added is expected in the engine area and "upteching" of existing engine families seems to be in order. In some cases, such as with 3- and 4-valve heads and balance shafts, market pressures will probably determine the ultimate use rate. The customer perception of cost/value tradeoff will be critical.

TECH-38. What percent of U.S.-produced light-duty vehicle engines will utilize the following valve train configuration in 1900 and 1995?

	Median Response		Interquartile Range	
Valve Train Configuration	1990	1995	1990	1995
Push Rod	50%	30%	45/60%	25/40%
Single Overhead Cam	40	50	35/45	45/55
Dual Overhead Cam	10	20	5/10	15/25

Selected Edited Comments

Expect 80% of dual overhead cam engines to have direct-acting rather than rocker-arm valve actuation.

Easiest and most logical as well as practical way of reducing vehicle weight has to come from engine weight reduction. This means all heads and blocks. Therefore, it makes a lot of sense to design next generation engines out of aluminum.

Discussion

There has been continuing interest in the valve train configuration in U.S. light-duty engines. Data suggest that the pushrod engine will be fading in popularity but will still be used in 30% of 1995 engines. The single overhead cam engine will be expanding to a level of 50% of market penetration in 1995 and the dual overhead cam configuration will expand to 20% of the 1995 market. These data suggest that there is a continued interest and support for "teching" of modern engines. The interquartile ranges on these forecasts are reasonably tight, indicating a relatively high degree of consensus.

Comparison of Vehicle Manufacturer and Supplier Panelists

The responses of the OEM and supplier panelists were identical. Additionally, the interquartile ranges for both groups were in close agreement, with a variance of no more than five percentage points.

Strategic Considerations

Probably one of the most important factors in selection of the engine valve train is perceived value on the part of the customer. At this time there is evidence that customers are expecting a higher level of technology in engines, but we wonder whether they are willing to support this level of technology, considering the higher cost that may be associated with this. Of course in most cases, the higher technology will yield a higher level of performance. An interesting trade-off remains for the U.S. manufacturers: that one can provide performance through higher engine displacement rather than through higher specific output characteristics of the engine. Foreign manufacturers generally do not have this flexibility in their domestic market because of the tax policies on displacement. The data suggest that there will be a spread of technologies in the valve train in the years ahead; suppliers interfacing with this part of the engine system will need to watch developments very carefully.

TECH-39. *The following is a two-part question.*

TECH-39A. What percentage of light-duty vehicle engines produced in the U.S. in 1990 and 1995 will utilize aluminum cylinder heads and/or blocks?

	Median Response		Interquartile Range	
	1990	1995	1990	1995
Aluminum Heads	35%	60%	30/40%	40/65%
Aluminum Blocks	10	15	5/10	10/20

MEDIAN FORECASTS FROM THREE DELPHI SURVEYS
U.S.-PRODUCED LIGHT-DUTY VEHICLE ENGINES WITH
ALUMINUM HEADS AND BLOCKS IN 1990

	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Aluminum Heads	50%	30%	35%
Aluminum Blocks	15	10	10

Discussion

Median responses indicate steady growth in the use of aluminum cylinder heads and blocks in light-duty vehicles produced in the U.S. The forecast is for 35% aluminum heads in 1990, growing to 60% in 1995. Paralleling this growth, alumınum blocks are forecast in 10% of the engines in 1990 and 15% in 1995. The interquartile range for 1990 is very tight, while the forecast for 1995 shows a much broader range, particularly on the lower end. The interquartile range for aluminum blocks for both 1990 and 1995 are tight, indicating a good consensus for the growth of aluminum blocks.

Comparison of Vehicle Manufacturers and Supplier Panelists

The two groups of panelists are in agreement on projections of aluminum blocks and heads in 1995. For 1990, the supplier panelists forecast 30% aluminum heads and the OEM panelists forecast only 5% aluminum blocks.

Comparison of Replies to MAT-11A

The Materials panelists forecast significantly higher utilization of aluminum heads and blocks than did the Technology panel.

	Percent Aluminum Heads			
	Median Response		Interquartile Range	
Panel	1990	1995	1990	1995
Technology	35%	60%	30/40%	40/65%
Materials	50	70	40/60	70/80
	Percent Aluminum Blocks			
Technology	10	15	5/10	10/20
Materials	20	40	10/20	20/50

Trend from Previous Delphi Surveys

From the 1981 Delphi II survey to the 1983 Delphi III, the forecast for the 1990 percentage of aluminum heads in U.S.-produced light-duty vehicle engines dropped 20 points. This has rebounded slightly to a Delphi IV forecast of 35%. During this same period, aluminum heads also experienced a slight forecast drop of 5%. The Delphi III forecast of 10% (with an even tighter interquartile range than the Delphi IV forecast) is the same as projected in this survey. The trend established from Delphi III and Delphi IV illustrates a stability in the forecast percentages for 1990 and gives a very good indication of the industry plans in this area.

Strategic Considerations

The substantial fraction of aluminum heads expected supports the high level of engine redesign noted earlier. Another key issue relates to the casting technology required to meet the demands of cost and more precise engine requirements.

The integral head/block engine may begin to emerge in the early 1990s and aluminum will be the material of choice in this design.

TECH-39B. Of the aluminum blocks (if any) forecast in 39A, please forecast the percentage of sleeving materials among the following.

Sleeving Material	Median Response 1990	Median Response 1995	Interquartile Range 1990	Interquartile Range 1995
Unsleeved	5%	10%	0/10%	5/20%
Cast Iron Sleeves	90	80	80/99	60/90
Others*	5	10		
TOTAL	100%	100%		
*Other sleeving materials forecast:				
Aluminum	15	15	5/15	10/40
Ceramics/Polymers	0	10	0/15	8/20
Unspecified "Special Coatings"	2	5	2/5	5/15

Discussion

Cast iron is expected to remain the dominant sleeving material through 1995. A slightly increasing trend in unsleeved engines is forecast through 1995. The sleeving materials cited under "Other" are worth noting. The interquartile ranges for both unsleeved aluminum blocks and cast iron sleeves are broad enough to indicate a significant degree of uncertainty about the median forecast. In view of this, special consideration should be given to the possibility of other sleeving materials occupying a percentage.

Comparison of Vehicle Manufacturer and Supplier Panelists

Supplier panelists forecast that only 1% of aluminum blocks would be unsleeved in 1990, although this percentage is bracketed by a wide interquartile range. The supplier panelists were in accord with the combined median forecast for cast iron sleeves, whereas the vehicle manufacturers forecast 85% for 1990 and only 70% for 1995.

Comparison of Replies to MAT-11B

The Materials panelists forecast a significantly higher use of unsleeved engine blocks than did the Technology panelists.

Panel	Median Response 1990	Median Response 1995	Interquartile Range 1990	Interquartile Range 1995
	Percent Unsleeved			
Technology	5%	10%	0/10%	5/20%
Materials	10	30	0/10	20/30
	Percent Cast-Iron Sleeves			
Technology	90	80	80/99	60/90
Materials	80	70	70/90	40/80

Strategic Considerations

It is evident that some of the early problems with unsleeved engines have not been put aside despite the success some foreign manufacturers have had with this design. With "proving" of unsleeved technology, it might be expected that unsleeved designs could expand beyond the forecast percentage. Emphasis on quality and longer warranty period will definitely make manufacturers cautious about introducing uncertain technology.

TECH-40. For the following engine components, please indicate possible materials/processes for their production by 1995.

Materials/Processes	Percent of Total Responses
Crankshaft	
Iron (ductile, modular)	
Cast/Shell Molded	70%
Forged	12
Steel	
Cast	9
Forged	9
TOTAL	100%
Camshaft	
Steel	
Machined/Fabricated/Forged	23%
Shell Molded/Cast	17
Iron (ductile, modular)/cast-forged	24
Powdered Metal	
Sintered	15
Forged/HIP	6
Steel and PM/Composite Assembly	6
Graphite Composite/Machined	3
Fiberglas	3
Ceramics	3
TOTAL	100%
Piston	
Aluminum	
Cast/Forged	44%
Squeeze Cast	7
No process designated	7
Aluminum-plastic	3
Aluminum-Fiber Reinforced	
Permanent mold casting	3
Squeeze Cast/Forged	6
SUBTOTAL Aluminum	70%
Ceramics	
Cast	3%
Sintering	3
No process designated	15
Ceramics-Plastic/Molded	3
Ceramic Crown with Plastic	3
SUBTOTAL Ceramics	27%
Composite (skirt)/Injection Molded, HIP	3
TOTAL	100%

Materials/Processes	Percent of Total Responses
Connecting Rod	
Steel/Forged	12%
Iron	
Cast	8
Forged	4
SUBTOTAL	24%
Aluminum	
Forged	6
Aluminum Alloy	4
Aluminum-Reinforced	8
SUBTOTAL Aluminum	18%
Powdered Metal	
Forged	8
Sintered	6
HIP	2
Injection Molded	2
Powdered Metal—Aluminum	
Forged	2
Powdered Metal—Al-Titanium	2
SUBTOTAL Powdered Metal	22%
Carbon Fiber	4
Fiber Reinforced	4
Carbon Composite—Machined	2
Composites	
Cast and Forged	2
Injection Molded	6
No process designated	4
SUBTOTAL	22%
Plastics	12
Ceramics	2
TOTAL	100%
Intake Manifold	
Plastic/Injection Molded	51%
Aluminum	
Cast	21%
Lost Foam	9
No process designated	7
SUBTOTAL Aluminum	37%
Steel/Fabricated	5
Stainless Steel/Fabricated	2
Iron/Cast	5
SUBTOTAL	12%
TOTAL	100%

Materials/Processes	Percent of Total Responses
Exhaust Manifold	
Stainless Steel	
Fabricated/Stamping/Welded/Tubular	29%
No process designated	12
Thin Wall Casting/Casting	5
Steel-Fabricated/Welded Stamped	12
Low Carbon Steel/Coated	2
SUBTOTAL Steel	60%
Iron	
Cast/Thin Wall	12
Lost Foam	8
Vacuum Formed	2
SUBTOTAL Iron	22%
Ceramics	
Liner/Coated	5
Slip Cast	2
Sintered	2
Injection	2
No process designated	5
SUBTOTAL Ceramic	16%
Aluminum/Lost Foam	2
TOTAL	100%
Rocker Arm Cover	
Plastic/Injection Molded	65%
Aluminum	16
Cast	2
Stamped	2
Aluminum/Plastic	2
SUBTOTAL Aluminum	22%
Sheet Steel/Stamped	9
Magnesium (no process designated)	2
Arm casted around ceramics	2
TOTAL	100%
Oil Pan	
Plastic/Injection Molded	62%
Aluminum	
Casting	14
Stamping	2
Aluminum-Plastic Composite	2
SUBTOTAL Aluminum	18%

Materials/Processes	Percent of Total Responses
Steel, Sheet Metal/Stamping	7
Laminated Sheet Metal (no process designated)	2
Magnesium	2
TOTAL	100%

Discussion

This question gives some indication of the use, in 1995, of various materials and processes for the production of eight major engine components. The replies are broken down by component so that the percentages forecast for each add to 100%.

Forecasts for possible materials and processes for the 1995 production of eight major engine components exhibit a wide variety of predictions. Crankshafts show the narrowest range with choices limited to cast and forged iron and steel. In contrast, connecting rod forecasts are broadly distributed across iron, steel, aluminum, powdered metals, and composites and include several processing choices such as forging, casting, injection molding, and machining. One of the interesting possibilities is the rise of ceramics in camshafts (3%), pistons (27%), connecting rods (2%), exhaust manifolds (16%).

Comparison of Replies to MAT-7

The identical question addressed to our materials panelists resulted in some significantly different replies, which are discussed below under component categories.

Crankshaft:	In addition to iron and steel, materials panelists mentioned aluminum (15%) and composites (5%).
Camshaft:	Many detailed differences but probably not of major significance in a ten-year forecast.
Piston:	Technical panelists emphasized aluminum more (70% vs. 46% for materials panelists) and plastics less. However, the rich variety of forecast categories, with many combinations (aluminum/plastic, aluminum/ceramic, ceramic/plastic, etc.) make comparisons difficult.
Connecting Rod:	Greater technical panel emphasis on powdered metal (22% vs. 4% Materials panel) and less on aluminum (18% vs. 38%).
Intake Manifold:	Steel and cast iron (combined) was 12% among technical panelists and only 4% for materials respondents.
Exhaust Manifold:	Less iron and steel are forecast of materials panelists.
Oil Pan:	Steel drops to 16% for technical panelists and 29% for materials panelists.

The rocker-arm-cover forecast was not asked of Materials panelists. They were asked about materials/processes for water pump housings and air cleaners while technical panelists were not.

Strategic Considerations

Obviously, the question of material choices is growing geometrically more complicated, difficult, and competitive. The main function of this question is to emphasize that point. The opportunities for automotive materials and process suppliers are equalled only by the pitfalls.

TECH–41. Polymer-based materials are already in use for engine components, such as rocker-arm covers and timing-chain covers. Indicate additional engine components which you consider the most likely to be built from these materials and their year of commercial introduction (30,000+ units).

	Year Commercial Introduction	
Engine Component	Median Response	Interquartile Range
Push Rods	1989	1989/1995
Oil Pan	1990	1990/1993
Throttle Bodies	1990	1990/1992
Rocker Arms	1990	1989/1995
Intake Manifold	1990	1990/1995
Piston Skirts	1995	1990/2000
Timing Gears	1995	1988/1995
Connecting Rods	1995	1992/1995
Valve Stems*	1990	
Fuel Rails*	1990	
Fuel Pump Housing*	1990	
Carburetion Parts*	1990	
Air Handling System*	1990	
Seal Retainer*	1995	
Pump Covers*	1995	
Piston Pins*	1995	
Drive Shaft (composite)*	1995	
Block (sections)*	2000	

*Denotes a single response.

Selected Edited Comments

Utilization of polymer-based materials will occur faster than our current crop of engineers will admit.

Discussion

Polymers may be used for a greatly increased number of engine components by the early 1990s. The first eight items listed are expected in commercial production between 1990 and 1995 (based on the median responses). Polymer-based push rod may appear before 1990. Components shown as single responses indicate the possibility of even broader applications of polymers to engine components. Since these panelists are in a position to make what they forecast achieve realization, even a single response deserves serious attention.

Strategic Considerations

A wide variety of additional engine parts made from various polymer-based materials is expected to reach commercialization in the next ten-year period. A few received rather broad support among the panelists and are indicative of important technological trends. Some of these components are rather sophisticated internal parts, such as connecting rods, piston skirts, and rocker arms, which would considerably benefit from lower weight and could potentially lead to reduced engine vibration and friction. A number of other parts received support from only a single panelist; however, it strengthens the notion that the broad potential of plastics in the engine is quite significant. Those that are building components with conventional technology are urged to pay very careful attention to materials trends and to watch for new non-traditional suppliers in their field to introduce components based on new materials technology.

TECH–41A. What percentage of U.S.-produced passenger cars and light-duty vehicles will utilize the following polymer-based engine components by the year 1995.

Polymer-Based Engine Components	Percent 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

Selected Edited Comments

Oil pans and valve covers are easily molded, have low stresses, and operate in reasonable temperature ranges. The other components do not offer these same advantages.

Ease of manufacturing should be advantage for plastics for the complex shapes of tuned intakes.

Comparison of Manufacturer and Supplier Panelists

The supplier panelists forecast that 15% of U.S.-produced vehicles will utilize polymer-based oil pans by the year 1995. This is in contrast to the OEM panelists who forecast 5% penetration for these same components. Otherwise there is no significant difference between the vehicle manufacturer and supplier panelists.

Discussion

This question attempts to provide a more quantitative indication of the penetration of plastics in engine components. Both the intake manifold oil pan and valve covers are expected to be produced from plastics in approximately 10% of the vehicles by 1995, with little support for connecting rods, piston skirts, and rocker arms. This would suggest that while the technology of plastics in these components will begin to emerge in the next ten years, significant momentum is not likely until beyond 1995. The interquartile range is reasonably close for all components, with the exception of valve covers.

Strategic Considerations

While there is limited support for polymer-based engine materials in the foregoing list, the rather wide interquartile range indicates that the technology could emerge and that once commercialization is attained, the basic economics and technical factors could drive the percentage very rapidly to much higher levels. Developments in areas such as these must be watched very carefully, particularly by traditional component manufacturers who have limited experience in other materials technologies.

TECH–42. With increasing emphasis on aerodynamics, tighter underhood packaging requirements, higher engine load factors, and other changes, what temperature increase do you foresee with respect to current vehicles in the years listed?

	Temperature Increase	
Vehicles in:	Median Response	Interquartile Range
1990	10°F	5/10°F
1995	10°F	5/20°F

Selected Edited Comments

Definite problem for electronics. Problem is underestimated at early design phase of vehicle, requiring "band aid" design improvements of electronics near job end. Need to estimate extent of problem at early design phase of vehicle by use of aerodynamic testing, fully loaded vehicle, and "production" location of parts established as early as possible.

By 1995, underhood air temperature control should be coming in.

Temperature increase can be expected if we run engines hotter than current design.

We now see 225°F (off-engine).

Adibatic combustion chambers and thermal barrier coatings will maintain or lower underhood temperatures.

Must be controlled to limit octane-related power losses and minimize sensor durability problems.

No increase. Ventilation and fans will improve underhood temperatures.

Requires upgrading of materials and capability of electronic components. This will limit the allowable increase.

Stop-gap "band aids," e.g., fans, pumps, etc., to limit the inevitable will eventually give way as heat-soak compatible materials become available. Electronics will require shielding.

Turbos will do much to increase underhood temperature.

By 1990, 300°F and by 1995, 320°F.

Immediate solution to reducing underhood temperature has to come from better understanding of aerodynamic flow and underhood venting techniques.

Better cooling techniques and thermal barrier materials will partially offset increases due to aerodynamics, etc.

Increased use of belly pan for aero splash protection, and noise abatement will aggravate problem.

Reliability already suffers due to high temperatures—must be reduced unless semiconductor technologies are invented.

Temperatures will stabilize again because of improved cooling techniques.

Discussion

The panelists forecast a 10° rise in underhood temperature in both 1990 and 1995. The wide interquartile range for 1995, particularly in the upper range, indicates a considerable degree of uncertainty about how high the temperature will reach.

Discussion of Panelists' Comments

The panelists' comments touch on underhood improvements to offset and control temperature. Some feel that these improvements will mitigate any significant temperature increases.

Comparison of Vehicle Manufacturer and Supplier Panelists

There is no difference between OEM and supplier forecasts for underhood temperature increase.

Trend from Previous Delphi Surveys

In 1983 the Delphi III panelists also forecast a 10°F temperature increase for 1990. The interquartile range is also the same as Delphi IV.

Strategic Considerations

Panelists indicate rather strongly that there will be continued increases in underhood temperature which will continue to increase the challenges of selecting materials for the underhood environment. This problem is exacerbated by the increasing demands for quality and reduced maintenance which provide an even greater challenge for underhood materials. Also it should be observed that the temperature in the underhood region is hardly constant. Areas near hot surfaces, such as the exhaust manifold, would be obviously considerably warmer than other parts of the chamber. Particularly serious thermal stresses are likely with polymer-based components and electronics. One could surmise that there may be a significant value-added opportunity in vehicles to provide more effective underhood temperature control. Of course, increasing air flow in this region could negatively impact aerodynamic drag. In older style vehicles, the underhood region accounted for about 10% of the drag on the vehicle.

TECH–43. What percent of U.S.-produced spark-ignited engines for light-duty vehicles will be either supercharged or turbocharged in model years 1990 and 1995?

	Median Response		Interquartile Range	
Gasoline Engines	1990	1995	1990	1995
Supercharged	1%	4%	1/2%	1/5%
Turbocharged	10	10	5/10	10/15

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
TURBOCHARGING AND SUPERCHARGING IN 1990

Gasoline Engines	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Supercharged	N.A.	5%	2%	1%
Turbocharged	25	10	10	10

Selected Edited Comments

Four-valve heads will usurp significant demand for boosted engines. Turbo refinements (ceramic rotors, variable geometry) vs. supercharger breakthrough is a tough call.

Four-valve heads will give similar power at lower cost.

Four valve is a better functional and cost alternative.

Comparison of Vehicle Manufacturer and Supplier Panelists

For 1995 supercharged engines, the OEM panelists forecast one-half of the percentage forecast by the supplier and the combined median (2% vs. 4%).

Trend from Previous Delphi Surveys

Forecasts for 1% supercharging by 1990 indicate a significant decline from the 5% forecast by Delphi II in 1981. The turbocharging forecast for gasoline engines experienced a dramatic reduction from a high of 25% in 1979 to 10% in 1981. However, this estimate of 10% has held steady through Delphi III and Delphi IV.

Strategic Considerations

The key comment concerning the relative cost of four-valve heads and turbocharging is probably very important with respect to auto manufacturer planning. Of course the turbo/supercharger options are attractive ways to increase an engine's effective displacement and horsepower output quickly and with low capital cost. They will probably continue to be used in this fashion.

Another key question relates to the tradeoff between boost and greater engine displacement. Increasing displacement is generally less costly than using external boost if a new engine is being tooled anyway.

TECH-44. What percentage of U.S.-produced passenger cars with spark-ignited engines will be produced with the following types of fuel management systems in the years 1990 and 1995?

	Percentage Passenger Cars			
	Median Response		Interquartile Range	
Fuel Management System	1990	1995	1990	1995
Fuel Injection:				
Throttle Body or Manifold (single point)	50%	40%	45/60%	30/50%
Port (Multipoint)	40	58	30/45	45/70
Carburetion	10	2	5/15	0/5
TOTAL	100%	100%		

MEDIAN FORECASTS FROM TWO DELPHI SURVEYS
FUEL MANAGEMENT SYSTEM MIX IN 1990

Fuel Management System	1983 Delphi III	1986 Delphi IV
Throttle Body	50%	50%
Port	25	40
Carburetion	25	10

Selected Edited Comments

As increased NOx and other emission regulations affect the need for more precise fuel control, only very light vehicles can get by with carburetors. Possible multifuel (methanol) capability if favorable legislation is instituted.

Some light-duty trucks will remain carbureted ... maybe some performance cars too.

Discussion

Throttle body or manifold fuel injection is forecast to hold at 50% on all U.S.-produced vehicles with spark-ignited engines. This is expected to drop to 40% in 1995. By this date, port or a multipoint fuel injection system is expected to achieve the majority share of fuel management systems. Carburetion is expected to continue its drop to 10% in 1990 and only 2% by 1995. The interquartile range is acceptable as providing a consensus, particularly on the lower interquartile range. The upper interquartile range for carburetion, however, is high enough to warrant attention, in that 25% of the panelists expect carburetion to occupy 15% or more of the market in 1990.

Comparison of Vehicle Manufacturer and Supplier Panelists

Manufacturer panelists expect that only 5% of U.S.-produced passenger cars will, in 1990, use carburetion as a fuel management system. Furthermore, this percentage is expected to drop to 0% by 1995.

Trend from Previous Delphi Surveys

The trend for throttle body or single-point fuel management systems to hold at 50% is consistent through both Delphi III and Delphi IV for 1990. The percentage of port or multipoint fuel management is expected to increase 15 percentage points over the previous Delphi forecast for 1990 at the expense of carburetion.

Strategic Considerations

It appears clear that the traditional spark-ignition-engine carburetor is rapidly fading from the scene. The only market opportunity in the future will probably be in aftermarket parts. Multipoint fuel injection is becoming the dominant system. Obviously those who are producing fuel-system components must watch fuel injection trends closely. A few parts are compatible with both systems, but most parts are unique to each system. There appears to be significant business opportunities in the fuel management system, although it can be reliably predicted there will be rather substantial pressures for cost reduction as the technology becomes more mature.

TECH–44A. What percentage of U.S.-produced light-trucks with spark-ignited engines will be produced with the following types of fuel management systems in the years 1990 and 1995?

	Percent Light Trucks with Spark-Ignited Engines			
	Median Response		Interquartile Range	
Fuel Management System	1990	1995	1990	1995
Fuel Injection:				
Throttle Body, or manifold (single-point)	50%	45%	25/60%	30/60%
Port (multipoint)	20	45	10/30	20/50
Carburetion	30	10	10/50	2/30

Selected Edited Comments

Light-truck manufacturers are slow in bringing engine technology to the auto level. Light trucks are perceived to be (and are) more price sensitive.

Discussion

Both port and multipoint fuel injection are expected to be used in an increasing fraction of light trucks. By 1995, approximately 90% will be equipped with either a port/multipoint fuel injection or throttle body injection. Carburetion will be used in 10% of 1995 units. The interquartile ranges on this question, which was asked in the second round, are broad, indicating considerable uncertainty on the part of the panelists.

Strategic Considerations

The application of fuel injection to light trucks is expected to trail the rate of application on passenger cars. Still, it is expected to grow dramatically compared to today to the point where it almost becomes a standard feature by the middle 1990s. This reinforces the opportunity in this very-high-volume segment for injection manufacturers and a considerably reduced market potential for carburetion systems.

TECH-44B. What changes/developments do you foresee in the *fuel management* systems of spark-ignited I.C. engines in the years 1990 and 1995?

Changes/Developments in Fuel Management Systems

1990

The panelists were almost unanimous in forecasting a general trend towards electronic fuel injection (EFI) with a variety of features as a development in fuel management systems by 1990. See "Representative Responses" below.

1995

The overwhelming majority of the panelists forecast a trend toward more precise and sophisticated fuel injection with a wider dynamic range and increased feature content. See "Representative Responses" below.

Representative Responses

1990

Greater shift toward mass air flow, closer integration of fuel and ignition microprocessing, sequential fuel metering.

Most will be computer-controlled fuel injection; primarily port injection with lower cost engines using throttle body injection.

Trending toward 100% fuel injection with more "bell and whistle" control.

Higher dynamic range systems.

On-board fueling vapor recovery.

Sophisticated transient controls.

Bottom-feed port injector.

Continual increase in use of microprocessor controls through the 1995 period.

Continuation of trend toward tuned intake systems with multipoint fuel injection.

Electric fuel pumps exclusively, most in tank. Better fuel injectors for port fuel systems. EFI multipoint gaining ground.

I expect some attention to a better throttle line process, i.e., a device with more stable flow than a butterfly valve.

Improvements in port injectors to reduce coking problems.

Increasing usage of fuel-injection systems (TBI and MPFI) to replace carburetors.

Improved fuel pumps.

Increasing applications of MPFI with tuned intake systems.

Low-pressure bottom-feed TBI with in-tank pumps will be principal system.

Mix of throttle body and multipoint injection with percentage of MPI increasing.

More use of modifiers such as detonation detectors and peak pressure sensors. More integration into rest of system.

More adaptive controls.

More cycle-to-cycle corrections during transient operation.

More port fuel injection, with control of time and duration of injection for each cylinder.

More sequential, more low-pressure TBI, improvements in fuel-injector reliability and spray pattern.

Move toward port injection timed with intake valve, plugged fuel nozzle problem solved.

Near elimination of carburetors and mechanical injection systems; continued reduction in component costs; increased use of multipoint on all V-8, V-6, and some four-cylinder engines.

Simplification with the introduction of artificial intelligence and variable valve timing.

1995

Adaptable to fuel changes.

All fuel injection with maximum controls—knock sensors, lean burn oxygen sensors, air flow sensors more accurate, other "state-of-vehicle" sensors to more accurately control maximum best fuel/air ratio.

Closer integration with electronic gearbox control and traction management.

Combined TBI and port systems.

Continuation of trend toward tuned intake systems with multipoint fuel injection.

Cylinder fuel-air ratio optimization, fuel preheating.

Fully electronic managed spark and fuel.

Further replacement of TBI systems on 4-cylinder engines.

Increased multi-port F.I. Some direct injection if stratified charge comes in.

Individually controlled fuel injectors.

Lean burn, lower cost port F.I. systems.

More capability to monitor fuel quality and correct fuel delivery to compensate for possible flex fuel (methanol/gasoline) capability.

More coil-on-plug systems with detonation sensor and individual cylinder spark advance control.

More diagnostics and redundancy.

More of the low-pressure bottom feed TBI with in-tank pumps.

More refinements of port injection and higher penetrations. Also better atomization.

New sensors and more complex control algorithms.

Discussion

In both 1990 and 1995 an increased use of electronic fuel injection is expected. Rather than categorize the individual feature content of this system, a large number of representative responses are included that suggest a wide variety of features anticipated, ranging from improved mass air-flow measurement, greater dynamic range, low-pressure bottom-feed throttle body injection systems, cylinder fuel-air ratio optimization, and a host of other features.

Strategic Considerations

The traditional carburetor is essentially disappearing as a primary element of the fuel management system, to be replaced by either throttle body or multi-point or port fuel injection. The variety of features expected is large and indicates a rather substantial number of opportunities for new componentry. The sophistication level in the system is obviously going to increase dramatically. Electronic control appears to provide an attractive cost/benefit ratio in the fuel management system, i.e., the benefits of precise and reliable control are achieved at a relatively low cost.

TECH-45A. What changes/developments do you foresee in the *ignition* systems of spark-ignited I.C. engines in the years 1990 and 1995? Please comment.

Changes/Developments in Ignition Systems

1990	1995
Increased use of direct-fire systems	Adaptive control
Higher energy	Individual cylinder control
Distributorless ignition systems	Lifetime-of-engine spark plugs
Individual cylinder control	Greater shift toward capacitive systems from inductive for reduced rise times
	More sophisticated direct-fire concepts, more precise control

Representative Responses

1990

Most will be solid-state direct-fire with self-sensed timing and computer-controlled advance.

Much greater use of direct fire, especially on double overhead cam four-valve engines.

Complete integration into engine control unit ECU; higher percent usage of closed-loop control systems.

Direct fire. A spark is a spark, and enhancement doesn't get much except increased cost.

Distributorless ignition with high-energy coils will progressively replace traditional distributors and coils.

Full electronic control of timing expected.

I expect a trend toward higher energy/faster rise systems to supplement dilute combustion.

Increased application of "direct fire" systems.

Increased accuracy and energy levels. More closed-loop/individual-cylinder control of ignition timing.

Individual cylinder control with knock sensors trimming the spark map for each cylinder.

Management systems for engine and transmission, optimization of operating characteristics.

Minor increases in displacement, more use of platinum in upscale vehicle spark plugs.

More distributorless systems, platinum tip plugs, more knock sensors.

Significant shift to distributorless ignition systems—some with coil-on-plug with detonation sensing capability/spark advance control on individual cylinders.

Trend toward fire with engine shielding high-voltage leads. Closed-loop timing control possible.

Ultra-short pulse.

1995

Adaptive control using microprocessors.
Cost reduced and expanded utilization of individual cylinder control with knock sensors trimming the spark map for each cylinder.
Closed-loop timing likely.
Cylinder-pressure-based systems.
Long-life spark plugs.
More electronic engine control integration.
Increased accuracy and energy levels. More closed-loop/ individual-cylinder control of ignition timing.
Individual coils for each spark plug will be introduced in some new systems. Some systems may be maintenance free, including spark plug.
Microprocessor-directed ignition (distributorless), cylinder-performance monitors. monitors.
More accurate control and higher-temperature initiators.
Multiple diagnostics.
Multi-spark systems.
Plasma ignition.
Some use of multiple cylinder-timing capabilities; that is, each cylinder is optimized with its own timing requirements—not the present compromise of all cylinders timed identically.
Some use of closed-loop combustion chamber peak pressure.
Spark duration varied.
Variable valve timing, ceramic pistons.
Virtually 100% usage of "direct fire" or similar systems.

Discussion

By 1990 there is expected to be a significant increase in use of direct-fire ignition systems with higher energy and, generally, a major increase in use of distributorless systems. Also, individual cylinder control is expected to appear. By 1995 more of what is forecast in 1990 is anticipated with the appearance of adaptive control and generally more advanced systems in every respect. In addition, changes such as important increases in spark plug life are anticipated. It is important to read through the "Representative Responses" to gain a sense of the varied suggestions on this question.

Strategic Considerations

It is evident from the data in this question that we are on the threshold of a revolution in spark ignition systems. Obviously, electronics will play a critical role but there appears to be a substantial threat to some of the existing engine components such as a conventional distributor. Furthermore, substantial new opportunities are suggested. All suppliers of engine components must watch trends very carefully with the high-level magnitude of change suggested in the basic technology.

TECH–45B. What percentage of U.S.-produced passenger cars with spark-ignited engines will incorporate the following ignition systems in the years indicated?

Ignition Systems	Percent U.S.-Produced Passenger Vehicles: Median Response 1990	Median Response 1995	Interquartile Range 1990	Interquartile Range 1995
Knock control/Adaptive controls	30%	55%	15/50%	30/75%
Distributorless ignition systems	20	50	10/30	30/70
Individual cylinder control of ignition	5	20	2/15	10/30
Coil-on-plug/Closed-loop timing control	5	15	1/10	5/30

Discussion

Distributorless ignition systems and knock control and adaptive control are forecast in 50% or more of 1995 vehicles. Lesser but significant support was noted for individual cylinder control of ignition and closed coil-on-plug systems. The interquartile range was very broad, indicating a high level of uncertainty.

Strategic Considerations

The four basic engine factors discussed in this question received strong support from the panelists and are obviously candidates for explosive growth in the next ten years. In most cases they probably would represent a degree of value added and could negatively affect some of the current ignition system and engine control componentry. Several of the technologies are reasonably well developed today, and it is inferred that with their cost reduced, they will be used far more broadly in the years ahead.

TECH-46. Which ceramic engine components will be used commercially (30,000+ units), not just experimentally, by 1995, in spark-ignition and diesel engines?

Ceramic Components: Spark-Ignited Engines	Percent of Respondents for Each Variable
Valve Train Components (including valves, inserts, guides, seats, tappets, cam, etc.)	71%
Exhaust Manifold and Port Liners	61
Turbocharger Turbine/Rotor	44
Piston Crown	15
Piston Rings (including coatings)	7
Pump Seals	7
General wear surfaces	5
None	7
Others: Rocker arm covers; Piston pins	7

Ceramic Components: Diesel Engines	
Piston Crown	45%
Valve train components (including valves, inserts, guides, seats, tappets, cam, etc.)	38
Combustion chamber (including prechamber)	35
Turbocharger Turbine/Rotor	21
Fire decks	2
Others: Above-the-rings cylinder insert; Piston rings; Rocker arm inlays; Bearings and seals; Port liners; Glow plugs	5

Representative Responses

SPARK-IGNITED ENGINES

Tappets, water pump seal, seat inserts in aluminum heads, main seal, guides in aluminum block.

Piston skirts, connecting rod, cam followers, piston dome inserts, wear pads for rocker areas, cam rollers, turbocharger rotor, ceramic insulated pistons.

Turbine impeller, turbocharger turbines.

Valve train parts where low friction, lightweight and wear resistance are important, coatings on piston rings, cam follower shoes.

Many value train parts for improved wear and/or lower mass. Reciprocating parts for lower mass.

Rocker arm inserts (cam-contact).

Valve train, valve tappets, valves, exhaust port liners, rocker arm covers.

DIESEL ENGINES

Perhaps limited usage of ceramics for combustion chamber insulation.

Piston bowls, head inserts, prechambers, rocker pads, valve guide and/or stems, valve seats, possibly valves, bearings exhaust liner to turbo.

Piston dome inserts, prechambers.

Rocker arms.

Cylinder walls.

Wear buttons in valve train, rocker arm wear pads, some heat insulating components such as valve seats and cylinder liners.

Combustion chamber parts that would reduce heat rejection to environment.

Combustion chambers (expanded to direct injection version) with ceramic pistons and chamber liners.

Insulated fire deck and piston crown just being introduced.

Many value train parts for improved wear and/or lower mass. Reciprocating parts for lower mass. Thermal control, e.g., exhaust ports.

Combustion chamber components for low heat rejection.

Discussion

This question provides a broad review of expectations for the commercial application of ceramic components for both spark-ignited and diesel engines. Also see MAT-9.

Comparison with Previous Delphi Surveys

In the 1983 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?* Despite the difference in the wording of the questions in the two Delphis, the results demonstrate a striking concurrence, i.e., the top five engine components for both spark-ignited and diesel engines listed in Delphi IV are essentially the same top five components listed in Delphi III. The median year forecast in Delphi III for these components to achieve commercialization was 1990.

Strategic Considerations

There continues to be optimism for ceramic materials in a variety of engine components. Of course it must be recognized that the in-chamber insulation qualities of ceramics in gasoline engines may not be as attractive as in diesel engines because of problems with engine octane requirement. It does appear that the applications are focused on relatively low-mass regions, although turbocharger turbine and piston crown are reasonably significant individual components. The major thrust seems to be in temperature control and friction/wear reduction. Obviously manufacturing considerations are extremely important with ceramic materials as is the long-term durability capability. We sense that there is a somewhat more focused optimism than in the past, but perhaps less optimism for the so-called total ceramic engine.

TECH–47. What percentage of gasoline will use the following for octane enhancement for the years 1990 and 1995?

	Median Response		Interquartile Range	
Octane Enhancement	1990	1995	1990	1995
No additives (additional refining)	80%	70%	60/90%	55/90%
Methanol	10	10	5/10	5/25
Ethanol	10	10	5/10	5/20
Others*	0	10	0/10	2/15
TOTAL	100%	100%		

*The following were suggested as other additives for octane enhancement: MTBE, MMT, and TEL.

Selected Edited Comments

Without tax incentives, ethanol couldn't compete economically until next major oil crisis.

Discussion

A modest percentage of the respondents, 20%, expect the use of methanol and ethanol as octane enhancers by 1990 and 1995. Presently, the use of these additives is declining and their penetration of the total gasoline market has never approached 20%.

The interquartile ranges on the various panel responses are broad, indicating uncertainty as to future expectations for materials to enhance gasoline octane.

Comparison of Vehicle Manufacturer and Supplier Panelists

Predictions were essentially the same for both groups.

Comparison of Replies to MAT-24

The two panels are in agreement on percentage share of fuels that will not use additives for octane enhancement in 1990.

Strategic Considerations

We were surprised at the rather modest expectation for methanol and ethanol as fuel additives for octane enhancement in gasoline because there is a generally substantial supply of alcohols, particularly methanol, in the world market and we expect continued pressures for its use as both a fuel extender and octane enhancer. Also, it is likely that the use pattern could vary substantially with geography in the country. We are convinced that this will be a very interesting development to watch. With even a modest fraction of fuel using methanol, manufacturers will have to build componentry in the fuel system that will withstand the rigors of methanol exposure.

TECH–48. 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.

	Very 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

Selected Edited Comments

Fuels from oil shale and tar sands are best bets.

Shale = moderate; tar sands = moderate.

Source of methanol depends on extent and duration of a petroleum shortage. Long-term alternate liquid fuel source most likely to be methanol from coal.

Discussion

Respondents were asked to rank possible motor vehicle fuel alternatives in terms of their likelihood of production in significant quantities in the event of a major and continuing interruption in international petroleum supplies. The most likely were considered to be methanol derived from natural gas or coal. Only hydrogen was considered to be highly unlikely.

Comparison of Vehicle Manufacturer and Supplier Panelists

In the "Very High" category for the likelihood of production in the event of an interruption in the flow of international petroleum supplies, the OEM panelists ranked methanol from both coal and natural gas at about fifteen percentage points higher than the supplier panelists. The supplier percentage responses in the "Very High" likelihood category for coal-derived petroleum fuels, natural gas, and liquid petroleum gas (LPG) are approximately 2.5–3.0 times those of the vehicle manufacturers.

Comparison of Replies from Previous Delphi Surveys

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 are 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 area of low to moderate. Natural gas rose from a strong unlikely in Delphi III to a more moderate to low position in Delphi IV.

Strategic Considerations

There is growing consensus that methanol is the alternative fuel of choice. Every manufacturer and fuel system component supplier should develop an appropriate methanol fuel strategy well in advance of a petroleum crisis.

TECH–49. 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 holes and fittings to handle it. More tank volume required. Low heating value per pound.

Low caloric value. Safety (invisible flame).

METHANOL: VEHICLE PERSPECTIVE

Advantages

Higher power output, higher compression ratio for higher energy efficiency.

Potentially lower emissions, except for aldehydes.

Potential for lower NOx and CO.

No significant emission problems.

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.

Expensive fuel system materials.

Materials incompatibility. Evaporation canister deterioration. Shifts in stoichiometry.

Corrosive effects on polymers.

Problems with reliable cold starting.

Discussion

The responses to the 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.

Comparison of Replies to MAT-26

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 principle advantage, the Technology panel was nearly unanimous in supporting this option.

Strategic Considerations

Based on the views of the panelists, there are a number of areas with respect to both the fuel and vehicle where problems are evident. However, none of these problems would appear to be fundamental, and therefore should not preclude expanded use of methanol as a fuel supplement, at least up to approximately a 10% level. The trend of availability and cost of petroleum will largely govern the future role of methanol. At present, methanol is widely available principally from waste natural gas. It is in oversupply on the world market and is consequently quite inexpensive.

TECH-50. What percent of light-duty engine oil will be synthetic in 1990 and 1995?

	Percent Synthetic Light-Duty Engine Oil	
	Median Response	Interquartile Range
1990	10%	5/10%
1995	20	10/25

Selected Edited Comments

Function of cost reductions—higher internal loads and longer intervals will push higher utilization and drive cost to be more competitive with oil.

Heavy-duty market should be somewhat better. Generally not cost effective except in extreme service (e.g., low temperature/high temperature, extended drains).

Discussion

By 1990, 10% of light-duty engine oil is forecast to be synthetic; by 1995 that percentage is forecast to double. The interquartile ranges are reasonably close and indicate a good consensus for both years.

Comparison of Vehicle Manufacturer and Supplier Panelists

The vehicle manufacturer forecast of the percent of light-duty oil that will be synthetic in 1990 is one-half that of the suppliers. In 1995, the OEM response is, at 10%, again one-half that of the supplier forecast of 20%.

Comparison of Replies to MAT-27

The Materials panelists forecast 5% of light-duty oil will be synthetic by 1990. Their respective responses for 1995 were identical.

Strategic Considerations

The difference in forecast between manufacturers and suppliers may be significant. The manufacturers, because of their primary design responsibilities for engines, should be reasonably close to lubricant trends. A systems approach in the design of lubricants and engines together could yield a different concept of future lubricants than is envisioned today.

TECH-51. In light of increased usage of new powertrain technologies such as turbocharging, four-valve and fast-burn engines, increased compression ratios, etc., what new requirements will oils for future light-duty vehicles have to address?

Oil Requirements	Percent of Respondents
Higher operating temperatures	79%
Better viscosity index	26
Longer oil change intervals	13
Resistance to higher levels of blow-by products	8
Increased oxidation resistance	8
Higher unit loading capability	8
Longer engine life	5
Higher unit pressure	5

Others:
- Higher octane ratings
- Higher speeds
- Higher detergent capability
- Better lubricating characteristics
- Better dirt and particle suspension
- Higher sustained operating speed
- More ring stick resistance
- Possible methanol combustion products
- Coking resistance
- Less phosphorus

Representative Responses

Engine must have lubricants which do not break down at 300°F.

The engine will require lubricants at 350°F to 400°F and not *carbonize.*

Somewhat tougher durability demands really need longer lube periods.

Sustained higher ring-belt temperatures; higher extreme pressure rating for greater engine dynamic loading; lower viscosity (without increased oil consumption), less deposit formation.

Greater thermo-oxidative stability; more rapid viscosity change capability.

Higher internal loading for cams and longer intervals for changes. Higher piston ring temperatures—more ring stick. Higher NOx and higher peroxides in blowby; higher unit loadings—valve train. Higher temperature duty cycles, longer change intervals; more Newtonian viscosity characteristics.

Longer change intervals: that's what customers tell us they want. More resistance to heat since one of the oil's main function is to cool in addition to lubrication.

Oils whose viscosity responds to location or surfaces in the engine, e.g., valve gear can use low viscosity oil while pistons would like high viscosity oil.

Stalle low-temperature viscosity characteristics. Wider viscosity range for cold starting with good wear protection.

Discussion

Panelists forecast that higher operating temperatures would be the major new requirement that oils will have to address for future light-duty vehicles. A better viscosity index and longer oil change intervals were additional future oil requirements receiving a substantial response from the panelists. In addition, the responses listed under "Others" represent the broad thinking of the panelists as well as addressing a constellation of added lubricant requirements.

Comparison of Replies to MAT-28

The two panels were in agreement that higher operating temperatures would be the major new requirement for future light-duty vehicle oils. Although the percent of respondents varied somewhat, they were also in general agreement regarding the remaining requirements cited.

Strategic Considerations

It is clear that panelists expect new engines to be more demanding of lubricants. This fact may be the key factor prompting increased expectations for synthetic oils. Higher specific power, tighter underhood packaging, higher load factors, added accessory loading are some of the other factors that could require improved engine lubricant quality. It would appear that additive packages will be particularly important to meeting the objectives of higher lubricant stresses and longer oil change intervals.

TECH-52. In light of expected technological changes in engines and transmissions, and problems with current designs, indicate three lubricant additives (based on type of problem) that you would like to see developed.

Engine/Transmission Problem	Lubricant Additive
Varnish formation	Anti-oxidant
High-temperature sludge formation	Acid resistant dispersants
Ring sticking	Improved viscosity index
Cylinder/ring wear	Anti-scuff friction modifiers
Better high/low temperature performance	Anti-scuff friction modifiers
Improved viscosity characteristics for automatic transmission fluid; better viscosity performance with temperature extremes	Anti-scuff friction modifiers
Longer change intervals	Anti-scuff friction modifiers
Reduce multi-viscosity oil wear on engine	Improved viscosity index
Dilution and contamination with dirt and water	Anti-contaminants
Friction/shear	Anti-friction
Deposits	Detergents
Wear and catalyst degradation	Non-phosphorous antiwear
Breakdown	Life extenders

Discussion

Several lubricant additives have been suggested by the panelists to meet various powertrain problems. The engine is the primary focus.

Strategic Considerations

There is a wide range of problems that our panelists would like to see addressed with improved lubricant additives. Significant opportunities for new and improved products are indicated. In general, forecast powertrain trends are based in part on the expectations for improved lubricant properties.

TECH-53. What minimum lubricant viscosity will be practical for 1995 light-duty vehicle engines?

	Median Response	Interquartile Range
Viscosity	5W30	5W30/5W30

Selected Edited Comments

However, heavy-duty service (e.g., trailer tow, desert operation, etc.) will require a 40 weight. Thus a 10W40 is also needed.

Future oil requirements will include low-temperature performance pumpability at 30°F and no decomposition at higher temperatures.

At 150°C, 3.0 CP and high shear should be minimum specification.

5W30 should be restricted to low ambient temperature (where it is indeed needed).

Discussion

The panelists responding to this question consider 5W30 to be the minimum viscosity practical for light-duty engines by the year 1995. Both upper and lower quartile ranges are also 5W30, indicating a very strong consensus: over 50% of the respondents made exactly the same forecast.

Discussion of Panelists' Comments

The first comment addresses the requirements for heavy-duty operation; the remaining comments relate to specific technical aspects of viscosity requirements.

Comparison with Previous Delphi Surveys

The same question was asked in Delphi III and the response was identical. This is one of the few areas where this degree of consistency has been seen.

Comparison of Replies to MAT-30

The two panels were in agreement that 5W30 will be the minimum viscosity practical for light-duty engines by the year 1995.

Strategic Considerations

It is evident from this Delphi forecast that there is a general and extremely tight consensus that the minimum viscosity for 1995 light-duty vehicles will be 5W and, in fact, the oil specification will be 5W30. There is no support for a less viscous oil. It is important to note, as observed in the comments, that other criteria related to the viscosity issue may be important in addition to assuring basic lubrication. Based on this tight consensus, this question may be put to rest for a while, though we should be watchful for new developments.

TECH-54. Do you foresee new lubricants for light- or heavy-duty engines that will extend:

Temperature Range:	The panelists were divided on forecasting the development of new lubricants for projected engine operating temperatures, with one-half projecting higher temperatures and the other half suggesting that the viscosity range should ultimately be slightly reduced to ensure consistent quality and reduced fuel consumption.
Oil Change Intervals:	The panelists were unanimous in forecasting longer oil change intervals.
Engine Life:	The panelists were unanimous in forecasting longer engine life.

Representative Responses

Temperature Range

Separators may be used on premium engines to improve oil performance and extend intervals.

For low-heat rejection engines: only exotic, very expensive synthetics can fluid-lubricate ring/cylinder; will require "solid ceramic lubricant."

Much higher, oil coolers may become standard.

Synthetics can extend range.

New material developments are expected for high temperature.

No. Do not expect much higher temperatures because of octane constraints.

Oil Change Intervals

Longer life—changing oil on a vehicle every 3-5K miles when other maintenance is at a 10-15K interval is incongruous.

Oil change intervals will be increased. Turbocharger technology will slightly reduce lubrication demands.

Add lubricant as required with no routine changes.

Can be extended with current and expected technology.

Extended—at least doubling in next ten years.

Longer, say 10,000 miles.

Looking for 15,000/20,000 miles.

Low maintenance marketing advantage to 7500+ drains is overwhelmed by disadvantages: (1) higher cost lubes needed, (2) erosion of engine life otherwise attainable. There is no incentive to increase drain interval, especially since people don't check oil level if they use self-serve fuel.

Should increase as a result of improved temperature range.

Yes, by improved filter design.

Engine Life

Oil quality will improve to offer optimized friction reduction.

A solid 100,000-mile engine is good enough.

Higher quality (non-synthetic) lubes will continue to make significant, but not obvious, cost-effective contributions.
Less maintenance but also shorter overall life.
Less tendency for film breakdown.
Little change from lubricants expected.
Should also improve with improved high-temperature resistance.
VI improves with low friction/low wear.
100,000 miles without repairs for automotive and 1,000,000 for heavy duty.

Discussion

Panelists expect, in general, that the basic requirements on lubricants for both light- and heavy-duty engines will be extended significantly in the years ahead with higher engine temperatures, extended oil change intervals, and higher level expectations for engine life.

Strategic Considerations

There is a clear indication that more will be expected of future lubricants in terms of extended oil change intervals, and exposure to higher temperatures. This occurs at the same time that consumer expectations in terms of quality and value are being extended considerably. One could suggest, therefore, that it will be increasingly important to view the engine and its lubricant as a system rather than to think of the engine designed to a given lubricant and a lubricant designed for a given engine. A higher level systems relationship will probably yield considerably improved overall performance. This also suggests that those who will be involved in the component or lubricant area will have to have a broader understanding of other ingredients in the overall engine lubricant system.

TECH-55. With expected changes in engine technology and fuel characteristics, what range of compression ratios do you expect for light-duty vehicle, spark-ignited engines in 1990 and 1995?

	Median Response		Interquartile Range	
	1990	1995	1990	1995
Maximum Compression Ratio	10	10.5	9.5/10	10/11
Minimum Compression Ratio	8	8.5	8/8.5	8.2/9

FORECAST FROM TWO DELPHI SURVEYS
COMPRESSION RATIOS

	1983 Delphi III	1986 Delphi IV	
Year	Average	Minimum	Maximum
1990	9.2	8	10

Selected Edited Comments

Fuel injection and fast burn have raised CR quickly already, pace has slackened to obtain low speed torque.

New higher speed engines (e.g., four-valve) and advanced-knock sensing will again push up CR. Knock sensing will allow boosted engine to approach naturally aspirated levels of CR.

Neat methanol as a fuel could raise CR to a maximum of 14:1.

The maximum is in use today (Jaguar) and more applications will occur. Higher CR will persist in spite of lower octane of available fuel due to better individual cylinder controls.

Discussion

Maximum compression ratios are forecast to be a median of 10.0 in 1990 and rise to 10.5 by 1995. Minimum compression ratio are projected to be 8.0 and 8.5 in the years 1990 and 1995, respectively. The interquartile range is reasonably tight.

Discussion of Panelists' Comments

The comments of the panelists address some of the technological factors affecting compression ratio requirements.

Comparison of Vehicle Manufacturer and Supplier Panelists

While both groups are in agreement on minimum compression ratios, the manufacturers forecast slightly higher compression ratios for both 1990 (10.0 vs. 9.8) and 1995 (10.5 vs. 10.0).

Comparison of Replies to MAT-32

The Materials panelists are in agreement with the Technology Panel forecast of maximum compression ratio for 1990 and 1995. However, they forecast a lower maximum CR for 1990 and a higher maximum CR for 1995 than did the Technology Panel.

Trend from Previous Delphi Surveys

The Delphi III projections of *average* compression ratios for given years are in line with Delphi IV forecasts and indicated a trend towards progressively higher compression ratios.

Strategic Considerations

Panelists expect fuel economy and performance demands to increase. The technology to support the increase should be available rather broadly in new engine designs. Fuel octane increases could also support higher compression ratios.

TECH-56. *The following is a two-part question.*

TECH-56A. What octane number do you foresee for the present gasoline grading system in the years indicated?

	Octane Number			
	Median Response		Interquartile Range	
Gasoline	1990	1995	1990	1995
Regular Unleaded	89	90	87/90	88/91
Premium Unleaded	94	95	93/94	94/95

Selected Edited Comments

A mid-grade unleaded fuel of 89 will be introduced. Octane needs of customers will be satisfied by shifts in regular to premium grade fuels, *not* by changes in fuel octane.

Achieving the consensus forecast, especially for 1990, would be a monumental burden on refining capacity. I just don't see it. A third grade is an intriguing possibility; it would solve octane pool problems, but most marketers would resist complicated three-grade logistics.

A chicken and egg situation. Increasing sales of premium will keep the octane pool tight.

Premium will hold levels but the regular will decline, reflecting feed stock quality.

Today's premium unleaded will be the only unleaded gasoline needed.

Discussion

Octane requirements for regular unleaded gasoline are expected to rise moderately to 89 in 1990 and 90 in 1995. The octane number for premium unleaded gasoline is forecast to be 94 in 1990 and rise to 95 in 1995. The interquartile range is reasonably tight, indicating a fair degree of consensus.

Discussion of Panelists' Comments

Comments touch several aspects of octane requirements. Of particular interest are those discussing a new third grade of unleaded fuel and potential problems in crafting higher octane fuels from existing refineries.

Comparison of Vehicle Manufacturer and Supplier Panelists

With the exception of an agreement for premium unleaded at 95 in 1995, the manufacturers forecast higher octane numbers than did the supplier panelists.

Trend from Previous Delphi Surveys

Delphi IV data continue the trend forecast in Delphi III of increasing octane requirements.

Strategic Considerations

It is evident from the forecast that panelists expect the quality of gasoline engine fuel to increase, based on octane number. This would appear to be supported by trends in engine design which will perhaps require increased octane by virtue of higher compression ratios and increased specific power. However, at the same time, new engine technology such as fast-burn combustion chambers and improved spark and EGR scheduling may moderate the octane increase. The increases, while modest, will certainly require some additional refining of unleaded fuel or the addition of octane extenders such as methanol or ethanol.

TECH-56B. For light-duty vehicles to be *sold* in the U.S. in 1990 and 1995, what is the expected segmentation between gasoline grades required by these vehicles?

	Gasoline Grades Required for Light-Duty Vehicles			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Regular Unleaded	90%	85%	80/90	80/90
Premium Unleaded	10	15	9/20	10/20
TOTAL	100%	100%		

Other single panelists' suggestions for fuel segmentation included a 5% share for alcohol mixes by 1995, a 1% share for super premium in 1990 and 1995, and a 5% share for diesel in 1990 and 10% in 1995.

Selected Edited Comments

Actual consumer use skews far more to premium than OEM required grade.

Advertised and actual fuel requirements may differ. Many "regular-fuel" engines with electronic spark control may need premium to run their best.

Depends on fuel availability and price. Most cars will be adaptive and will run on regular with reduced performance and economy or on premium with increased performance and economy.

I expect combustion systems and electronic controls to reduce octane requirements.

Usage rates are higher for premium, but this answers the manufacturers' requirements. Current premium usage is over 25% in 1985.

Discussion

The panelists forecast that of the light-duty vehicles sold in the U.S. in 1990, 90% will require regular unleaded gasoline. This percentage is expected to decrease to 85% by 1995.

Discussion of Panelists' Comments

Through their comments, the panelists raise the point that although only 10% to 15% of the light-duty vehicles sold in the U.S. in 1990 through 1995 will be OEM graded for premium unleaded, new, advanced engine designs may require premium grades for consumer-perceived optimum operation and efficiency.

Comparison of Vehicle Manufacturer and Supplier Panelists

The vehicle manufacturer panelists consistently forecast higher octane requirements than did the supplier panelists whose forecasts were also lower than the combined technology panel medians.

Comparison of Replies to MAT-33B

The Materials panelists forecast a larger market segment for premium unleaded than did the Technology panel (20% in 1990 and 25% in 1995).

Strategic Considerations

The expectations for greater fuel octane rating support the forecast of higher compression ratios. New engine technology and high-octane fuels could support sufficient increases in compression ratio to yield significant fuel economy and power gains.

TECH-57. What percentage of U.S.-produced passenger cars will use the following drivetrain configurations in the listed years?

		Median Response		Interquartile Range	
Drivetrain Configuration	Est. 1985	1990	1995	1990	1995
Front engine, rear drive	37.8%	25%	17%	20/30%	10/20%
Front engine, front drive (FWD)	61.0	71	76	65/75	70/80
Front engine, 4-wheel drive*	0.2	2	5	1/5	2/10
Mid engine, rear drive	1.0	2	2	1/2	1/4
Rear engine, rear drive	0.0	0	0		
TOTAL	100%	100%	100%		

*Also addressed in separate question Tech-25.

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
U.S.-PRODUCED PASSENGER CAR
DRIVETRAIN CONFIGURATION IN 1990

Drivetrain Configuration	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Front engine, rear drive	25%	15%	20%	25%
Front engine, front drive (FWD)	75	85	77	71

Selected Edited Comments

Mid engine, rear drive in 1995 will probably be mostly four-wheel drive (i.e., high power sports cars).

The "4WD" will be "all-wheel drive" in premium applications for the most part, with road performance, not off road, being the key selling point.

Four-wheel drive will make a surge during the next ten years.

Discussion

The former standard arrangement of front engine with rear-wheel drive is expected to decline from an estimated 38% of U.S.-produced passenger cars in 1985 to 25% in 1990, and only 17% in 1995. Front-engine, front-wheel-drive (FWD) is rapidly becoming the standard configuration and is forecast in 71% of the U.S.-produced passenger car market in 1990 and 76% in 1995. Mid-engine passenger cars are expected to double their share from an estimated one percent (1%) in 1985 to two percent (2%) in both 1990 and 1995. No rear-engine, rear-wheel drive, U.S.-produced passenger cars are forecast to appear on the scene by 1995. The interquartile ranges in two-wheel drive cars is wide except for front-engine/front drive.

Forecasts for front-engine, four-wheel-drive indicate a dramatic increase in the percentage of the vehicles, rising from an estimated 0.2% in 1986 to 2% in 1990 and 5% in 1995. The interquartile range on a percentage basis is particularly broad for 1995, indicating that the uncertainty is high.

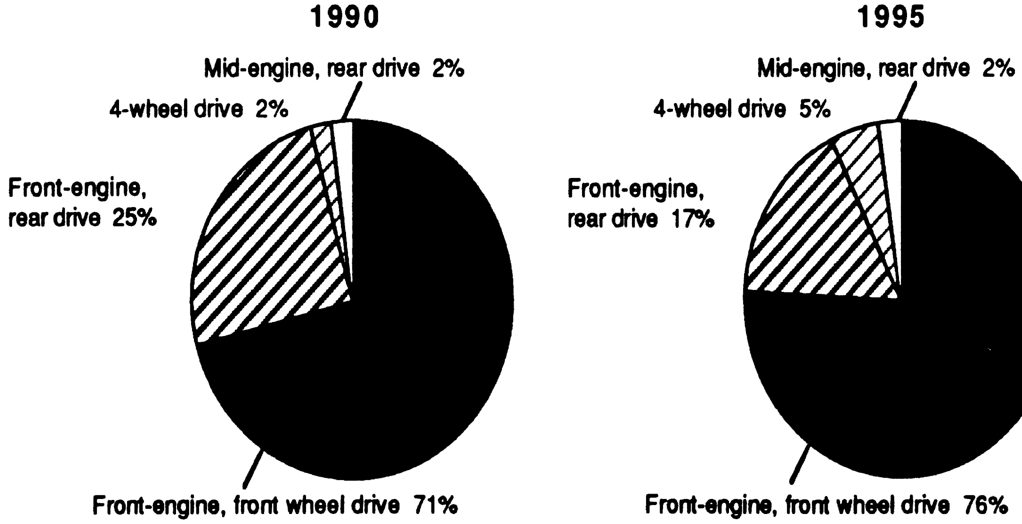

FIGURE T-7. Percent Drivetrain Configuration in 1990 and 1995 in U.S.-Produced Passenger Cars

Discussion of Panelists' Comments

The panelists' comments reflect the forecast that four-wheel-drive (4WD) automobiles will continue to make inroads in the U.S. market and create significant opportunities for drivetrain component suppliers. Front engine/front drive is obviously expected to continue as the dominant drivetrain configuration.

Comparison of Replies to MKT-6

Marketing panelists forecast that a 2.5% (interquartile range of 2/3) share of the passenger car market will utilize four-wheel drive in 1990 and 3.5% (interquartile range of 2.5/5) in 1995. This is in reasonable agreement with the Technology panelists' projection for 1990, but is 1.5% lower than the 1995 forecast. Interestingly, the Marketing forecasts are in reasonable agreement with the Technology suppliers' forecast for both years, but, like the suppliers, are significantly less than the manufacturers' projection for 1995 and the combined technology median for the same year.

Comparison of Vehicle Manufacturer and Supplier Panelists

The manufacturers and suppliers are in close agreement with regard to the median percentages for front-engine, rear-drive; front-engine, front-wheel-drive (FWD); mid-engine passenger cars; and the 1990 four-wheel-drive forecasts. Additionally, the interquartile ranges for the first two groups are almost identical. With regard to the 1995 forecast for four-wheel-drive vehicles, the OEM panelists project a percentage of 5% (interquartile range of 5/10) while the supplier panelists forecast only a 3% market share (interquartile range 2/9). These are not major differences.

Trend from Previous Delphi Surveys

Panelists participating in the Delphi II survey forecast that by 1990, 15% of U.S.-produced passenger cars would be front-engine, rear-drive; Delphi III forecast 20%, and current Delphi IV projections are for 25%. Although they have dropped from approximately 38% in 1985 to an estimated 29% in 1986, the Delphi IV forecast indicates a leveling off of this decrease to a 25% share in 1990.

In retrospect, the Delphi II forecast of 85% for front-engine, front-drive cars by 1990 and the Delphi III forecast of 77%, now appears to have been overly optimistic. It would seem that from an estimated 70% in 1986 to a Delphi IV forecast of 70% for 1990 and 74% by 1995, the considerable expectations of just a few years ago for front-wheel-drive cars continues to slowly fade. This in part may be due to capital conservation by the industry.

Similarly, the earlier Delphi III forecasts that mid-engine, rear-drive cars would account for 3% in 1990 and 4% in 1992 of U.S.-produced passenger cars also appear to have been overly optimistic. Panelists participating in Delphi IV forecast that mid-engine, rear-drive cars will represent 2% of U.S.-produced passenger cars in both 1990 and 1995.

Strategic Considerations

A greatly improved fuel supply/cost situation and dramatic technological improvements in powertrain/drivetrain efficiency have apparently revived consumer interest in larger passenger vehicles and sporty, high-performance front-engine, rear-drive cars, and tempered earlier predictions of rapid loss of market share for these vehicles.

Front-engine, front-wheel-drive cars are expected to continue a modest increase from an estimated 71% in 1990 to 76% in 1995. Considering the fluidity of the marketplace, attention should be paid to the forecast interquartile ranges. However, any increase in the actual percentages towards the upper quartile range would almost surely come at the expense of increased four-wheel-drive and mid-engine model percentages.

Forecasts from the Technology panelists and their comments indicate that close attention should be paid to four-wheel-drive vehicles. If just the median forecasts hold true, this would indicate a rapidly growing market. If, however, the upper quartile projects should come to pass, it would have a dramatic impact on the marketplace share for both rear- and front-drive-only drivetrain configurations. The customer must be closely watched here. If the market expanded beyond the "tech" and solid "need" buyer, the fraction could expand significantly. Price is likely to be a key determinant.

It should be noted that the four-wheel-drive forecast is significantly lower in this question than in Tech-25 which specifically addresses four-wheel drive.

Apparently because of confusion in the marketplace over what type of niche mid-engine, rear-drive cars should occupy, whether sporty performance and/or sporty commuter, there appears to be some retrenchment in the projections of current Delphi panelists as to how large a percentage of U.S. passenger cars this configuration will achieve. Nevertheless, it is clear from the forecasts that continued growth can be expected through 1995.

TECH-58. Indicate your expectations for the percentage use of various passenger car transmission types in the vehicle classes listed below for 1990 and 1995.

	Median Response					
	Conventional Automatic		CVT		Manual	
EPA Vehicle Class*	1990	1995	1990	1995	1990	1995
Mini/Subcompact	40%	40%	0%	5%	60%	55%
Compact	65	65	0	0	35	35
Midsize/Large	90	95	0	0	10	5
	Interquartile Range					
Mini/Subcompact	35/48%	35/48%	0/1%	2/10%	50/60%	50/60%
Compact	60/65	60/70	0/0	0/2	34/40	30/40
Midsize/Large	90/95	90/95	0/0	0/0	5/10	5/10

*This is the first Delphi survey in which we are using EPA classification rather than a constantly changing industry classification. See page 18 for a cross reference of passenger car models by EPA vs. industry classification.

MEDIAN FORECASTS FROM TWO DELPHI SURVEYS
1990 TRANSMISSION TYPES, U.S.-PRODUCED CARS

	Conv. Auto.		CVT		Manual	
EPA Vehicle Class	1983 Delphi III	1986 Delphi IV	1983 Delphi III	1986 Delphi IV	1983 Delphi III	1986 Delphi IV
Mini/Subcompact	40%	40%	5%	0%	55%	60%
Compact	75	65	0	0	25	35
Midsize/Large	95	90	0	0	5	10

Selected Edited Comments

Foreign-owned U.S. plants will bring along an increased manual share—despite movement upscale. General market will be more "creature comfort" oriented than previously projected; but sporty compacts will get manuals. Midsize sports models might be expected, due to "poshness," to go all automatic. But consider imports (Saab, Audi, etc., and especially Merkur).

Likely to see new concepts in automatic transmissions such as electronically shifted manual for less expensive cars.

By 1995 conventional automatics will have become more efficient and smoother operating. They will replace some manuals in specialty cars.

Present CVT efforts are not substantial enough for management to commit to production. Management mind-set not CVT oriented ... by the year 2000, maybe.

Discussion

Within the midsize to large vehicle class, the automatic transmission is forecast to be in 90% of the passenger cars in 1990 and 95% of the cars in 1995. In both 1990 and 1995, conventional automatic transmissions are expected to be utilized in 65% of the compact vehicle class passenger cars, with the remainder made up of manual transmissions. Mini/compacts are forecast to be 40% automatic in both 1990 and 1995, with 5% being CVT in 1995.

The interquartile ranges represent a good consensus of opinion, with the exception of the 1995 forecast for CVTs, where the interquartile range reflects the uncertainty surrounding CVT application that has been expressed elsewhere in this Delphi (see Tech-61, Tech-62).

Discussion of Panelists' Comments

The comments of the panelists represent a spectrum of opinion regarding the future orientation of transmissions. The last comment, in particular, presents an interesting perspective on CVT application. The comment on electronically shifted manual transmissions would suggest a hybrid transmission might be on the horizon.

Comparison of Vehicle Manufacturer and Supplier Panelists

There were no significant differences between the forecast of the manufacturer and suppliers with the single exception of transmission application for midsize/large vehicles in 1995, in which the manufacturers forecast twice the percentage of manuals: 10% vs. 5%. The interquartile range, however, for both groups is the same (5/10).

Trend from Previous Delphi Surveys

Delphi III panelists forecast 5% CVTs for mini/subcompacts in 1987 and 20% CVT application in mini/subcompact vehicles by 1992. Midsize and compact cars were expected to be 10% CVT. This is in contrast to current Delphi IV projections, which forecast only 5% CVT application in mini/subcompact by 1995. Projections for conventional automatic transmission from Delphi III are consistent with projections from this Delphi through 1995. Factoring out the inflated forecast for CVT in Delphi III, there appears to be no significant deviation in transmission type mix through 1995 presented in Delphi IV.

Strategic Considerations

Relatively modest changes in transmission application are envisioned. However, new technology, e.g., electronic manual transmissions or CVT (assuming rapid solution of current problems) could undoubtedly result in modest shifts in the forecast by 1995.

Above all, the customer will be key with the growing role as the market "driver." The market, with more products available than customers, will prompt all manufacturers to be sensitive to market shifts. The overall powertrain, including the transmission choice, is likely to be increasingly important to the customer.

TECH-59. Forecast the mix of transmissions for passenger cars manufactured in the U.S. in 1990 and 1995.

	Percent of Total Transmissions			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Manual				
Four Speed	10%	5%	10/15%	4/15%
Five Speed	20	25	15/25	20/30
Total Manual	30%	30%	26/35	25/33
Automatic				
Three Speed	30%	20%	20/35	14/25
Four speed	40	48	39/45	45/55
Continuous Variable (CVT)	0	2	0/1	1/5
Total Automatic	70%	70%	64/74	76/75
TOTAL	100%	100%		

MEDIAN FORECASTS FROM THREE DELPHI SURVEYS
1990 TRANSMISSION MIX, U.S.-PRODUCED CARS

Manual	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Three Speed	1%	0%	N.A.
Four Speed	18	15	10
Five Speed	13	15	20
Total Manual	32%	30%	30%
Automatic			
Three Speed	16%	27%	30%
Four Speed	42	35	40
Continuous Variable (CVT)	10	8	0
Total Automatic	68%	70%	70%

Selected Edited Comments

Automatic transmission will be electronically shifted five- and six-speeds.

Six speed is possible.

Greater use of lock-up in three-speed automatic transmissions.

Discussion

The overall (U.S.-based production) transmission mix is expected to hold at about 30% manual and 70% conventional automatic through 1995. Within the manual transmission category, four speeds are expected to decline in production percentage from 10% in 1990 to 5% in 1995 with growth in five speeds making up the difference. Among automatic transmissions, the three speeds are also forecast to experience a significant decline from 30% in 1990 to 20% in 1995, with four-speed automatics rising to 48% of the passenger cars' production transmission mix by 1995. No real growth is forecast for continuously variable transmissions until beyond 1995.

The interquartile ranges indicate reasonable consensus for most transmissions. However, on a percentage basis, the interquartile forecast range for the CVT and three-speed automatic and manuals may be significant.

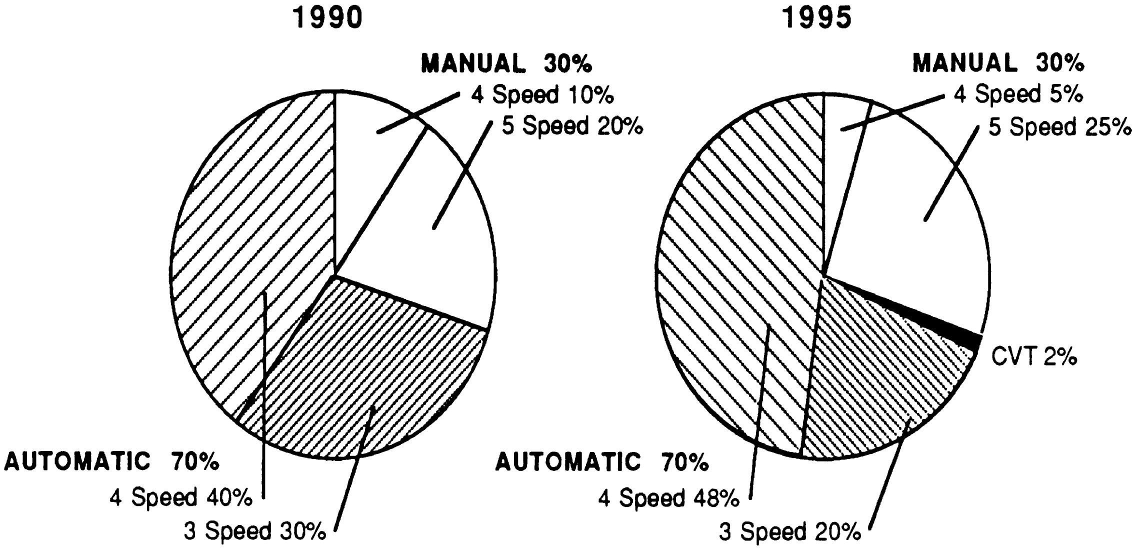

FIGURE T-8. Transmission Mix for U.S.-Produced Passenger Cars in 1990 and 1995

Discussion of Panelists' Comments

The comments suggest the introduction of a six-speed automatic transmission and there is still optimism for CVTs.

Comparison of Vehicle Manufacturer and Supplier Panelists

The OEM and supplier responses exhibit a substantial degree of consensus in both median and interquartile range.

Trend from Previous Delphi Surveys

The major observation in the trend data is the decreasing forecast for CVTs from a Delphi II projection of 10% for 1990 to 8% in Delphi III to the present Delphi IV forecast of 0% in 1990. The Delphi III expectation of 14% use of CVT transmissions in 1992 was overly optimistic, considering the present forecast of only 2% by 1995. The forecast production ratio of automatic transmissions to the manual transmissions of 70%:30% for 1990, however, has remained approximately constant from Delphi II to the present Delphi IV.

Strategic Considerations

It is clear that, with the exception of the CVT, panelists have only modestly altered their forecast of the overall transmission mix. However, the great optimism for the CVT has diminished considerably. One must remember that even as the CVT projection has faded, it could expand again if technical problems are resolved.

As noted in Tech-58, market forces could be very influential with regard to transmission mix.

Increasingly the consideration of the powertrain as a true system may result in the skewing of the forecast. For example, new engines with very "flat" torque curves coupled to three-speed automatics might match the performance of other engines with four-speed automatics. The cost implications could be significant.

TECH-60. What are the principal problems with current U.S.-produced light-duty vehicle transmissions?

Principal Problems with U.S.-Produced Light-Duty-Vehicle Transmissions	Percent of Respondents
Durability	47%
Shift Quality (including overdrive search)	41
Reliability	21
Noise	12
Manufactured Quality	9
Lack of Torque Capacity	9
Efficiency (poor fuel economy)	9
Driveability	6
Complexity	6
Lock-Up	6
Others:	
Serviceability	
Lack of electronic control for optimized shifting	
Car/engine mismatch	
Too early production release	

Representative Responses

Lack of ratio coverage, durability.

Automatics: shift quality, noise. Manuals: durability, poor shift quality, noise.

CVT product development has been extremely slow. CVT concept is torque limited (applies to small engines only). Automatic four-speed transmission cost is high compared to A3 and manuals.

Driveability—lack of smoothness.

Durability! Drivers tend to wind up small engines to achieve performance. This puts stress on transmission components such as clutch parts, etc.

Front-drive, four-speed automatics do not have good reliability/ durability records.

Manual transmissions are "rough." Automatics have poor fuel economy.

Manuals are not high quality.

Manual: shift quality. Automatic: Hunting between third and overdrive or lock up.

Poor driveability at lower engine speeds.

Poorly matched to car/engine for performance/economy.

Released for production too soon.

Lack of torque capacity for increased performance engines.

Reliability and durability are not up to expectations for "world-class quality." Also, "business" of frequent shifting common to overdrive transmissions and/or clutched converters is frequent driveability complaint.

Shift quality, durability, poor ratio-to-torque curve matching, poor scheduling (for automatics), lock up/overdrive search (for automatics).
Poor cross-section design.

Discussion

Generally the responses are self-explanatory. However, it is evident that a range of quality problems is present and this list provides a relative ranking. This question does not address what fraction of transmission have quality problems.

Shift quality, durability, and reliability issues dominate. More detailed problem areas that received less support in most cases are subsets of the top three concerns.

Strategic Considerations

While this question does not address the incidence of quality problems with present transmissions, it is evident from other sources that this is a significant concern. It is clear that all manufacturers are aggressively pursuing quality improvements on existing designs, and important progress has been made. The quality improvement appears to be the primary focus today rather than introduction of significantly new designs.

Furthermore, it must be recognized that all problems do not apply to every transmission; but the strong support for shift quality, durability, and reliability suggest that these problems are reasonably general.

TECH-61. At the present time there is a major production problem with the drive belt of the continuously variable transmission (CVT). By what year do you foresee this problem being solved?

CVT Drivebelt Problem	Median Response Year	Interquartile Range Year
Resolved	1990	1989/1992
Not Resolvable (4% total responses)		

Selected Edited Comments

Some CVTs will be sold in the U.S. prior to the problem being solved, certainly by Subaru, perhaps by Ford.

Will be only considered for very low output and lightweight vehicles.

Chain drive will not be Van Doorne type.

Expect long development time to prove high mileage durability before auto manufacturers are willing to risk "high" volume application.

Ford's concept car "ELTEC" had a CVT transmission with a belt which could overcome this problem. Fiat will be marketing an ECVT, produced by Fuji, on its 900–1000 cc Panda and Autobianchi cars.

I believe a chain-type element will prevail in approximately five years (sufficiently developed for production-vehicle installation).

Oil glut is disincentive. Even with belt solutions, commercialization will be slowed.

Replacement/maintenance will always be a deterrent to acceptance.

Resolvable for low end torque requirements.

Small quantities in 1990 in small vehicles (1–1.56 cc) developing by 1995 to significant (30% of autos).

The CVT can be made to work on very small, low-powered cars. The trick is to make it work on real cars.

The Van Doorne belt design is too complex for volume production. Look for breakthroughs in polymer-based designs.

Discussion

Ninety-six percent (96%) of the panelists responding to this question believe that problems associated with the drive belt of the CVT will be resolved. The median year for this resolution was forecast to be 1990 with a good interquartile range of 1989 to 1992. Four percent (4%) of the respondents did not feel that current problems with the CVT would ever be resolvable.

Discussion of Panelists' Comments

The panelists' comments suggest that while drive-belt problems may be resolved in the early 1990s, the belt may not be of the Van Doorne type. It is further suggested that likely design breakthroughs will be polymer based. Additionally, the type of vehicle likely to see commercial application of CVTs, at least initially, will be small and lightweight with low volume output. A significant proportion of the panelists suggest that difficulties will remain in the application in larger engine displacement vehicles.

Comparison of Vehicle Manufacturer and Supplier Panelists

The OEMs and suppliers are in general agreement that 1990 will be the year in which major production problems with the CVT will be resolved.

Strategic Considerations

The major barrier to CVT commercialization appears to be the segmented belt. Obviously any supplier involved in transmission components must watch trends very closely. Based on the prior Delphi's enthusiasm for the CVT, there is at least the potential that it could have a major impact on future drivetrains.

TECH-62. Assuming a CVT is in production by 1995, what will be the maximum engine displacement and vehicle weight for a vehicle with a CVT?

1995 CVT Vehicle	Median Response	Interquartile Range
Engine Displacement	2.0 liters	1.8/2.5 liters
Vehicle Weight (dry curb weight)	2250 lbs	2000/2500 lbs

Selected Edited Comments

CVT is likely to remain a mini/subcompact car transmission until a third-generation product is available—post 1995.

CVTs will improve by the year 2000 with larger engine/vehicle capabilities.

Discussion

The panelists forecast that 2.0 liters would be the maximum engine displacement for a vehicle with a CVT by the year 1995. The interquartile range is fairly close at 1.8 and 2.5 liters. The dry curb weight of such a vehicle is projected to be a median of 2250 pounds with a reasonable interquartile range of 2000 to 2500 pounds.

Discussion of Panelists' Comments

The panelists' comments reflect the opinions expressed in Tech-61.

Comparison of Vehicle Manufacturer and Supplier Panelists

The vehicle manufacturer and the supplier panelists are in accord on a median displacement of 2.0 liters as the maximum engine displacement for a CVT. They are in disagreement, however, on maximum vehicle weight, with the manufacturers forecasting 2500 pounds and the suppliers forecasting 2000 pounds. The interquartile ranges of the two groups were identical at 2000/2500.

Strategic Considerations

There is a consensus that although the continuously variable transmission will be commercially viable within the next few years, it will remain limited to small displacement vehicles until new technologies are able to expand CVT capabilities to larger, heavier vehicles. These innovations would appear to be focused in the area of new belt-drive design, perhaps utilizing new generations of polymers/composites. However, the current oil surplus, significant improvements in engine and conventional automatic transmission efficiency, and the introduction of new materials and design innovations contributing to weight reduction would appear to inhibit expanding commercial application of the CVT.

A strategic consideration expressed in Delphi II appears to be relevant today: *It will be important for those with an interest in CVT to watch developments closely not only in the U.S. but also in Europe and Japan.*

It should also be noted that if the upper quartile range of vehicle weight and engine size for CVT application comes true, the CVT could have a future in a significant fraction of future products.

TECH-63. Name new automotive electronic/electrical advances that you expect to reach commercial application (30,000+ units) by 1990 and 1995.

The forecasts presented here represent the combined responses of the body/chassis, powertrain/drivetrain, and combined technology panels. A review of the "Representative Responses" is strongly recommended to give insight into the many electronic/electrical advances forecast by the different panels. Of course, several of the technologies suggested have attained commercialization today based on our definition.

ELECTRONIC/ELECTRICAL ADVANCED FORECAST TO REACH COMMERCIAL APPLICATION BY 1990

The following electronic/electrical advances forecast to reach commercial application by 1990 represent over 70% of the total responses of the panelists.

Active Suspension
Anti-Lock Braking System
Body/Engine Diagnostics
Electronic Power Steering
Electronic Transmission Controls
Multiplexing
Navigation/Information Systems
Power Convenience Controls

The following rank-ordered electronic/electrical advances forecast to reach commercial application by 1990 represent over 20% of the total responses of the panelists.

Traction Control
CRT Displays
Electronic IP Displays
Electronic Keying
Collision Avoidance
Cellular Phones
Advanced Entertainment Systems
Hands-Off Phones
Brushless Drive Motors
Drive by Wire.

Other responses each accounting for 1% or less of the total responses are as follows: limited serial link data; link control of vehicle electrical loads; video cameras for rear vision; fiber optics; distributorless ignition; variable nozzle turbo; valve timing; electronically controlled cooling; more computer capability, software controls; peak pressure (cylinder) closed loop; compact disk players; shared microprocessors; networking; efficiency improvements due to materials development; wiring diameter reduction; integrated displays; optically coupled and transmitted control signals; electronic commutation of electric motor; smart power switching.

Representative Responses

Body/Chassis Panel

Solid state power switching multiplexing

"Memory" control and convenience adjustments

More power requirements for the automobile such as for more electrical defrosting of glass surfaces

Power adjusted pedals

Touch control displays for car functions

Electric mirror and seat adjustment programmed for each driver

Electronic headlight dimmers, head lamp actuators, door locks

More sensors to monitor various car functions

Electronic oil level sensor

Tire pressure indicator

Brushless motors for blowers

Computerized map displays

Loran navigation

Color CRTs, graphic consoles, electro-illuminance for clusters

Cellular phones with hands-free voice recognition

Integrated in-dash cellular phones with integrated AM/FM phone antenna

Theft-proof electronic keys

Military aircraft-type projection instrumentation

Proximity warning

Compact audio disc players

Powertrain/Drivetrain Panel

Anti-skid, slip control

Better digital (electronic) instrumentation; LCDs and electroluminescent; more ABS systems

Bi-directional communication between microprocessors (time division multiplex; engine computer, body, service computer)

Transmission control—trucks as well as passenger cars.

Integrated vehicle controls (powertrain, braking, suspension, steering)

Integrated—only one on-board microprocessor, engine/transmission/options/accessories

Non-stoichiometric oxygen sensors for lean burn

Combined Technology Panel

Integration of brakes, steering, and suspension: anti-drive, anti-roll, dynamic control; integration of four-wheel-drive and ABS brake systems electronically with engine/transmission for all-wheel control—like newest Mercedes systems

Multiplexing of non-safety items

Computer-assisted maintenance/diagnostics

Transmission shift control, acceleration traction control

ELECTRONIC/ELECTRICAL ADVANCES FORECAST TO REACH COMMERCIAL APPLICATION BY 1995

The following electronic/electrical advances forecast to reach commercial application by 1995 represent approximately 60% of the total responses of the combined panels.

Multiplexing
Navigation/Information Systems
Integrated Vehicle Control Systems
Electronic Suspension/Ride Control
Electronic Power Steering
Collision Avoidance Systems
Electronic Transmission Controls

The following rank-ordered electronic/electrical advances forecast to reach commercial application by 1995 account for over 25% additional responses of the panelists.

Cellular phones
Fiber Optic Systems
Voice-Activated Controls
Anti-Lock Braking Systems
Heads-Up Displays
Entertainment Options
Flat Panel Displays
Advanced HVAC Systems
Drive by Wire

Other responses accounting for less than 1% of the total response are as follows: keyless entry; four-wheel drive; variable-ratios transmission control; movable pedals; 24-volt electrical system; improved night vision; keyless ignition; solar-powered ventilation; cooling for parked cars; automatic "memory" adjustment of controls and comfort; maintenance on demand; closed-loop spark and A/F control; temperature sensors; rear-view TV; silicon micro machining; electrically managed chassis; low-tire sensing; variable valve train; brushless DC motors; coolant thermostat.

Representative Responses

Body/Chassis Panel
Modular electronic hardware and software architecture
New electronic power-generating, storing, and delivery devices
Smart accessory drive motors
Smart windows for adapting to environmental conditions
Extensive serial data link control of vehicle electrical loads
GPS navigations
Electric steering tied to active suspensions
Smart struts
Cellular telephone in remote areas using satellites
Low-cost cellular telephone service
Integration of engine and vehicle electronic systems for total management of vehicle systems
More electronic control of systems such as brakes and suspensions
Vehicle seat-interior preheat systems
Distance-sensing systems (front and rear)

Digital audio tape
Laser disk data storage
Radar alarms for impending impact

Powertrain/Drivetrain Panel
All power assists, spark/fuel management, transmission control, complete diagnostics, on-board computer, guidance/mapping/location of car
Beginning of multiplexing
Bi-direction communication as above with contention protocol, increased integration, multiplex vehicle wiring
Computerized maps and directions, diagnostics, maintenance on demand
Electronically controlled transmissions, brakes, suspension, steering, cooling, and integration with A.I.
Heads-up display of vehicle parameter—fuel, speed, etc., voice control of accessories, radar braking
Integrated low cost total vehicle electronic controls
More integration of components
Portable/replaceable entertainment and business features (i.e., telephone, compact disc player, personal computers, etc.)
Satellite-based location, radar or optical collision avoidance
24/30-volt electrical systems
Local area networking

Combined Technology Panel
Active suspension system control at each corner—response to bounce/rebound with instantaneous control of suspension dynamics
Full integration of vehicle dynamics (acceleration, braking, handling) automatically with environmental conditions, i.e., friction coefficient of surface, and proximity of other vehicles
Higher voltages for electrical system 24–48 v.

Discussion

An incredibly wide range of responses were given to this question, reflecting the varying background of panelists from the powertrain, body/chassis, and combined technology groups. Furthermore, it is evident that many of the items forecast have already attained commercialization to a certain extent, but undoubtedly will be generally available and more refined in the years ahead. For example, anti-lock braking systems and cellular phones are both expected to expand dramatically in usage. Anti-lock braking, for example, is expected to attain over 50% penetration in the early 1990s. It is also clear that the range of electronic applications is very broad in the vehicle.

Strategic Considerations

The foregoing list of electronic-related technologies represents a wide range of items. In several cases the technologies have already reached commercialization, based on our measure of 30,000 units. However, appearance on the list may be an indication that significant growth is anticipated.

With competitive conditions as they exist today, more and more product differentiation is likely to be based on technological factors. Thus no automotive electronic technology should be dismissed without serious consideration. With the diverse background of our panelists, even a single mention of a technology may be important. It is also important to note that terminology and definitions associated with automotive electronics is not completely standardized, making it difficult to collect and categorize the various technologies. Broadly speaking, two types of technology panelists contributed to the present Delphi: powertrain and body/chassis experts. The comments from these panels are kept separate as they have somewhat different perspectives on future trends.

Above all, it must be emphasized that a plethora of electronic-based features will expand their automotive role in the next five to ten years. There are few vehicle systems that will not require a fundamental role for electronics.

TECH-63A. What percent of U.S.-produced passenger cars will employ the following electronic/electrical-related features by the years 1990 and 1995?

	Percent U.S. Passenger Cars			
	Median Response		Interquartile Range	
Electronic/Electrical Features	1990	1995	1990	1995
Anti-Lock Braking System	15%	40%	10/20%	20/50%
Advanced Body/Engine Diagnostics	15	40	10/30	20/70
Electronic Transmission Control	10	25	5/20	15/50
Electric Power Steering	5	15	2/10	10/25
Traction Control	5	15	1/10	10/25
Drive by Wire, Electronic Control	1	5	0/5	3/15
Variable Valve Timing	1	10	0/5	5/15

Selected Edited Comments

Electronic transmission control: computer control of converter lockup will be nearly universal (90% of automatics). Full electronic (including shift timing and quality) will be much lower (10% or so). Variable valve timing: only variable camshaft phasing (like current Alfa Romeo system).

With computers on 100% of U.S. vehicles, all will carry some diagnostic capability.

Discussion of Panelists' Comments

The second comment has profound implications for dealer-repair service and do-it-yourself aftermarket.

Comparison of Vehicle Manufacturer and Supplier Panelists

There is no significant disagreement between the vehicle manufacturers and the suppliers on the percent utilization of these features.

Strategic Considerations

The above electronic components represent major subsystems that were forecast in question Tech-63 to reach commercial application by 1995. The data presented here gives a better understanding of the market penetration for these features.

TECH-63B. What percentage of U.S.-produced passenger vehicles (cars, vans, and light trucks) will utilize the following electronic/electrical advances in the years indicated?

	Percent U.S.-Produced Passenger Vehicles			
	Median Response		Interquartile Range	
Electronic/Electrical Advances	1990	1995	1990	1995
Power-adjusted convenience controls	30%	40%	15/50%	20/60%
Electronic transmission	10	30	5/20	20/50
Multiplexing	8	20	5/10	15/35
Cellular phones	7	15	3/10	10/25
Electronic keying/Personalized entry	5	15	5/15	10/30
Navigation/Information systems	3	10	1/5	5/15
Heads-up display	3	8	1/5	5/10
CRTs	3	5	1/5	5/10
Collision avoidance	1	5	0/3	4/10

Selected Edited Comments

Most of these items are high ticket items that will appear only in low-volume/high-tech vehicles.

Recent announcements of capital constraints will restrict introduction of these technologies, particularly those that do not offer the car buyer perceived or actual value.

Discussion

This question was asked to develop a more quantitative measure of the extent of various electronic-based technology installations in the years 1990 through 1995. While a number of factors are viewed as being relatively minor, others received strong support for future years. For example, power-adjusted convenience controls are expected to expand from 30% utilization in 1990 to 40% in 1995, and electronic transmission control from 10% of U.S.-produced transmissions in 1990 to 30% in 1995. Multiplexing is expected in 20% of 1995 vehicles, whereas electronic keying, personalized entry, and cellular phones were forecast to be in 15% of 1995 vehicles. In general, this is a rather ambitious expansion of electronic-based equipment in future vehicles. The interquartile range, measured on a percentage basis, is rather broad, indicating that there is substantial uncertainty on most features. It is clear, however, that the consensus even of the lower quartile is toward a rather significant increase in the utilization of these technologies.

Discussion of Panelists' Comments

Panelists' comments generally focus on basic economic considerations as being a strong factor in determining the penetration of the various electronic-based technologies. We would judge that these are certainly appropriate comments for the factors in this question.

Strategic Considerations

The expected future penetration of the technologies suggested in this question implies that, in most cases, we should see a rapid percentage growth in practically all of the factors. While in no case is the majority of U.S.-produced passenger vehicles expected to incorporate these technologies, strong growth suggests major business opportunities. Also, it is evident that this growth rate could support the forecast of fraction of vehicle cost that it is expected to be in electronic componentry. It must be noted, however, that in some cases we may had been expecting an even higher rate of application. Although these are just a sampling of electronic-based features, they tend to show that the trend to electronic involvement in the vehicle is increasing. One technology, the cathode ray tube, was forecast to have very modest growth, perhaps because of recent negative reaction to CRT types of displays.

TECH-64. What fraction of total vehicle dollar value in *today's* U.S.-produced passenger car is represented by electronic componentry, and what will it be in 1990 and 1995?

	Median Response	Interquartile Range
Today	10%	8/11%
1990	15	10/20
1995	20	15/25

Selected Edited Comments

Presently, the largest use of electronics is in the engine area. Interior electronics is just appearing in low-volume/high-tech vehicles. These interior components are usually high-ticket packages in the high-end cars (Pontiac STE, Buick Riviera, Cadillac Eldorado). Also, they are customer perceived as digital instruments, automatic climate control, and CRT touch screens. Very little electronics is being used in areas that customers do not see (wiring, motors, doors, etc.).

Only functional electronics will be used. "Arcade games" electronics is behind us.

Think you'll see more functional componentry, e.g., engine controls, suspension, etc., and less hype such as CRTs.

This is a tough question because of decision on: (1) how to define electronic components; (2) cost of electronics keeps going down; (3) semi-conductor technology will be used in other electronics.

Content will be higher only if costs come down, allowing features to be added at little increase in costs.

High-line vehicles will have a greater fraction and base/entry vehicles will have a smaller percentage.

Content and electrical complexity will increase, but costs will decrease, resulting in no change.

Might go *down* in constant dollars due to process technology and systems integration.

More electronics content but price of electronics continues to fall. Therefore, more content for same dollars.

Content will grow faster than ability to control cost: braking, ride, heated windshields, electrically controlled transmissions, digital driver multiface, new switching, etc.

Discussion

Electronics are an integral and rapidly growing part of the modern motor vehicle. The cost of electronics is estimated by the panelists to represent 10% of the total vehicle dollar value today. This percentage of total vehicle cost is forecast to rise to 15% by 1990 and 20% in 1995. The interquartile range is tight, indicating a good consensus.

The 15% forecast for 1990, when multiplied by the forecast median price of a car in 1990 (see Mkt-5) of $12,500, results in an electronic dollar share of $1,875. The Marketing Panel forecast for median car price of $13,800 by 1995, when multiplied by the projected 20%, results in a dollar share for electronic componentry of $2,760.

Discussion of Panelists' Comments

The panelists' comments reflect the knowledge that although the cost of individual electronic units and components is decreasing, there remains a remarkable capacity for growth and the introduction of new technologies.

Comparison of Vehicle Manufacturer and Supplier Panelists

The forecasts presented by the two groups are essentially in agreement.

Trend from Previous Delphi Surveys

This question was not asked in Delphi II but it did appear in Delphi I and Delphi III. At the time of Delphi I in 1979, it was expected that electronics would represent 15% of the cost of the vehicle by 1990. In 1983, Delphi III projected an electronic component cost of 10% of total vehicle cost. At that time the 5% decrease from the Delphi I forecast was interpreted to mean that cost would drop faster than use increased. One would assume that in the intervening years, economy of scale has reduced the individual cost of components. The current forecast of 15% can then be interpreted as a very substantial overall increase in the use of new electronic componentry.

Strategic Considerations

It is clear from the response to this question that explosive growth is expected in the overall application of electronics in light-duty vehicles. The panelists today believe that approximately 10% of the total cost is in electronics, with a doubling occurring by 1995. Results demonstrate significant differences between the body/chassis and powertrain panels. The size of the forecast is particularly interesting in light of the expected trend to component integration, reduced cost for individual components and memory, and other economies that will probably be achieved in the future. This is obviously offset by the major increase in electronic-based features from anti-lock braking to electric/electronic power steering. Note, however, as indicated on the next question, that these estimates may be overly influenced by consideration of high-tech vehicles. Differences in the interquartile ranges should not cloud the fact that overall expectations for electronic technology are very substantial in terms of the economics of future vehicles.

TECH-65. 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			
	Median Range		Interquartile Range	
	1990	1995	1990	1995
Lower Technology/High Volume	8%	10%	5/10%	10/15%
High Technology/Lower Volume	15	20	12/20	18/30

Selected Edited Comments

We need to learn to use technology to reduce cost instead of increasing vehicle content.

As electronic technology advances and mass production of electronic systems takes hold, unit costs will decline.

Electronic componentry in the engine area should be the same in the high volume/low volume. Electronic instrument panels, flat panels, and suspension controls will show up mostly in the "high-tech/low-volume" cars. With microprocessor systems, there usually is an initial "buy in" that can only be recovered with higher content and/or options which usually appear in the high-tech/low-volume cars.

Increased electronics content will be at same total cost. As electronics costs come down, usage will increase. Total cost of car will not increase.

To remain viable, electronics cost must continue to decrease.

Low technology/high volume will be value driven; high tech will be designed to meet the market influenced by an age group totally comfortable with computer and other electronic devices.

Discussion

The panelists forecast that by 1990 the percentage of total vehicle cost represented by electronic componentry will be 8% for lower technology/high volume cars and 15% for high technology/lower volume cars. By 1995, this percentage is expected to increase to 10% and 20%, respectively. The interquartile ranges are broad, indicating there is considerable uncertainty. In part this is a result of combining data of two different panels, the body/chassis and powertrain/drivetrain panels. Also, note that the high-tech forecasts here are the same as for the "average" car, shown in the preceding question. Whatever the difference, belief in substantial growth appears unanimous.

Comparison of Vehicle Manufacturer and Supplier Panelists

The median forecasts presented by the OEM and supplier groups are almost identical, with similar interquartile ranges.

Strategic Considerations

The electronic revolution is expected to expand rather dramatically, particularly in the higher technology/lower volume vehicle. Forecast electronic growth in the lower-technology vehicles is considerably less than in the higher-technology passenger cars. Obviously, substantial opportunity for new products is evident. The marketing panel forecast of split for these volume segments is 70% low-tech and 30% high-tech vehicles in the 1990-1995 time period.

While we certainly have some reservations in attempting to disaggregate the vehicle types according to two classes mentioned, it is perhaps useful to see the wide difference in expected electronic role in the future. There is no question that the high-tech specialty vehicle will be based on the broad range of advanced electronic technology.

It should be noted that the Marketing panel had reservations with respect to this product segmentation approach.

TECH-66. On a dollar value basis, what will be the vehicle manufacturer's make/buy ratios for *electronic hardware* (including sensors and actuators)?

	Median Response		Interquartile Range	
Vehicle Manufacturer	% Make	% Buy	% Make	% Buy
General Motors	60%	40%	50/65%	35/50%
Ford Motor Co.	40	60	40/50	50/60
Chrysler	25	75	20/30	70/80
AMC-Renault	5	95	2/10	90/95
VW of America	5	95	2/10	90/98
Japanese companies in U.S. (including joint ventures)	15	85	10/30	70/90

Selected Edited Comments

GM's acquisition of Hughes will increase its make/buy ratio.

VW will get its hardware from Germany.

VW and Japanese 100% buy is from non-U.S. suppliers.

Three U.S. domestic manufacturers are fully integrated (GM, Ford, Chrysler) with large internal capacity. AMC and VW purchase outside. Japanese companies import due to more favorable cost advantage (U.S. compared to Japan).

Renault no longer has interest in Renix. Japanese subsidiaries. i.e., Nippon—Denou assumed to be completely separate companies.

Future outsourcing will be heavily determined by UAW negotiations.

Discussion

The panelists suggest rather strongly that the automotive manufacturers will buy a significant portion of electronic componentry from the outside supplier base. The expectations for General Motors, Ford, and Chrysler closely parallel the marketing panel expectations for levels of vertical integration of the three companies, with GM maintaining the highest level of integration, followed by Ford, then Chrysler. The other manufacturers are expected to place even greater reliance on outside-sourced electronic componentry. The interquartile ranges in this question range from relatively broad to rather tight, but generally suggest that the median responses represent future expectations.

Discussion of Panelists' Comments

The panelists' comments are directed at special situations and tend to support the overall results expressed in the table. Certainly, acquisitions such as Hughes and other relationships will affect the make/buy ratio of the manufacturers.

Comparison of Vehicle Manufacturer and Supplier Panelists

The only significant difference between the vehicle manufacturer and supplier panelists exists in their respective forecast for Japanese companies in the U.S.; the OEMs forecast a 10%/90% make/buy ratio, whereas the suppliers forecast a 20%/80% make/buy ratio.

Strategic Considerations

Based on the expected dollar volume in electronic componentry, it is evident that the magnitude of the market for outside suppliers of the traditional manufacturers is extremely large in the electronics area. One key question from a systems basis is: Who will play the primary systems role in the electronics area? Will the manufacturers maintain a high level of systems capability and buy discrete components, or will more of the systems integration responsibility be directed to the supplier community? Where the suppliers are expected to take a higher-level system responsibility, it certainly suggests that they will then, in turn, have to maintain a much higher level of engineering or technology capability that covers the vehicle system.

TECH-67. In U.S.-produced passenger cars and light trucks, what fraction of the cost of the following major vehicle systems will be represented by *electronic components*?

	Electronic Components: Percent of Total Cost			
	Median Response		Interquartile Range	
Passenger Car Systems	1990	1995	1990	1995
Comfort, convenience, entertainment	40%	50%	35/50%	45/60%
Engine/transmission	10	15	10/15	15/20
Chassis/suspension	5	15	5/10	10/15
Safety	5	10	5/10	10/15
Other:				
Brakes	5	12	1/10	1/15
Electronic power steering	5	10	5/10	10/12
Light Truck Systems				
Comfort, convenience, entertainment	25%	35%	20/30%	25/40%
Engine/transmission	10	15	10/10	12/15
Chassis/suspension	5	10	2/5	5/10
Safety	5	10	3/10	5/10
Other:				
Brakes	2	7	1/25	2/10
Electronic power steering	2	7	1/5	2/10

Selected Edited Comments

Much of the electronic value added is already evident in engine/transmission. Largest growth will be in comfort, convenience, and entertainment and also in chassis/suspension. Passenger cars will lead light trucks in electronics applications.

Electrically assisted steering and anti-lock braking will become important items with every manufacturer. These features will incorporate significant electronic content.

The largest gains will be in comfort, convenience, and entertainment. Personalized cars along with home-type sound systems should prevail. The next largest gain will be in anti-lock brakes, four-wheel steering, speed-sensitive and electric power steering. Safety-oriented increases will be in passive restraints, air bags, and proximity warning devices.

The majority of safety-related electronics will be passive restraints.

Discussion

In passenger car comfort, convenience, and entertainment, electronics are expected to represent 50% of the cost by the year 1995. Similar growth in electronic costs are expected in light trucks, although at a slightly lower level in comfort and convenience and chassis/suspension. Brakes and electric power steering received responses for "Others" sufficient to warrant a considerable growth through 1995. These normally could be included in the chassis/suspension area but are kept separate because of the high frequency of their mention.

The interquartile range is fairly close in most areas, indicating a reasonable level of certainty.

Discussion of Panelists' Comments

The panelists' comments touch on a number of specific features which are expected to demonstrate considerable growth in terms of electronic componentry.

Comparison of Vehicle Manufacturer and Supplier Panelists

The OEM panelists forecast a 10% higher percentage in 1995 for comfort, convenience, and entertainment features in both passenger cars and light trucks than did the supplier panelists. For chassis/suspension features in light trucks represented by electronic componentry, the manufacturers forecast only 2% and 5% for 1990 and 1995, respectively.

Trend from Previous Delphi Forecasts

For the most part, the forecasts in Delphi III are consistent with Delphi IV. The decrease in the percentage forecast for 1990 in Delphi IV, when compared to Delphi III, for comfort, convenience, and entertainment and safety, may represent a perception on the part of the current panelists that although there may be an increase in the actual utilization of electronic componentry by the various systems, a continuing reduction in the unit cost of this componentry will result in an actual reduction in the percentage of total system cost.

Strategic Considerations

It is evident, as supported by one of the comments, that the engine transmission role for electronics is already becoming reasonably mature. However, an important exception should be observed with the expected increasing future role of electronics in transmission control. Also, we should keep in mind the difficulty of categorizing features into different subsystems. For example, one might consider an anti-lock braking system a part of either the safety or chassis suspension group. In any event, this question does provide a guideline, in terms of the basic vehicle breakdown that we have provided, as to the expected fractional role of electronics, based on system cost.

TECH-67A. Of that fraction of electronics cost, what will be the breakdown among the following vehicle systems?

	Percent Vehicle Systems			
	Median Response		Interquartile Range	
Lower-Technology/High-Volume	1990	1995	1990	1995
Engine	30%	25%	20/40%	20/35%
Audio and other entertainment systems	30	30	20/50	15/30
Transmission and drivetrain	10	15	5/20	10/20
Driver information (diagnosis, navigation)	10	10	5/10	5/15
Safety/Convenience	9	10	5/10	5/10
Vehicle control (anti-skid, suspension, four-wheel steering, etc.)	5	7	1/10	5/10
Other vehicle systems	6	3	5/13	5/10
TOTAL	100%	100%		
High-Technology/Lower-Volume				
Audio and other entertainment systems	30	25	15/40	20/30
Engine	25	20	15/30	15/25
Transmission and drivetrain	10	15	10/15	10/20
Driver information (diagnosis, navigation)	10	13	5/20	10/20
Vehicle control (anti-skid, suspension, 4-wheel steering, etc.)	10	13	5/18	10/20
Safety/Convenience	10	10	5/10	7/10
Other vehicle systems	5	4	5/10	4/7
TOTAL	100%	100%		

Discussion

The distribution of electronics between the various vehicle systems is developed for both lower-technology, high-volume vehicles and high-technology, lower-volume vehicles. In both instances, the distribution is relatively the same, although the engine is expected to utilize a generally greater fraction of the total electronic cost in the low-tech vehicles. Obviously, emission and fuel economy constraints which apply to both segments are a driving force here. The interquartile ranges are relatively broad, indicating a reasonable degree of uncertainty. In general, those factors which relate to future content are most strongly suggested of the higher tech vehicles.

Strategic Considerations

It can safely be assumed, based on this forecast, that vehicles in all segments will be profoundly affected by electronic technology. In some cases, regulatory issues are undoubtedly the driving force, such as in safety and engine and powertrain systems. In other cases the future demands by customers, which are dependent on electronic technology, are the driving force.

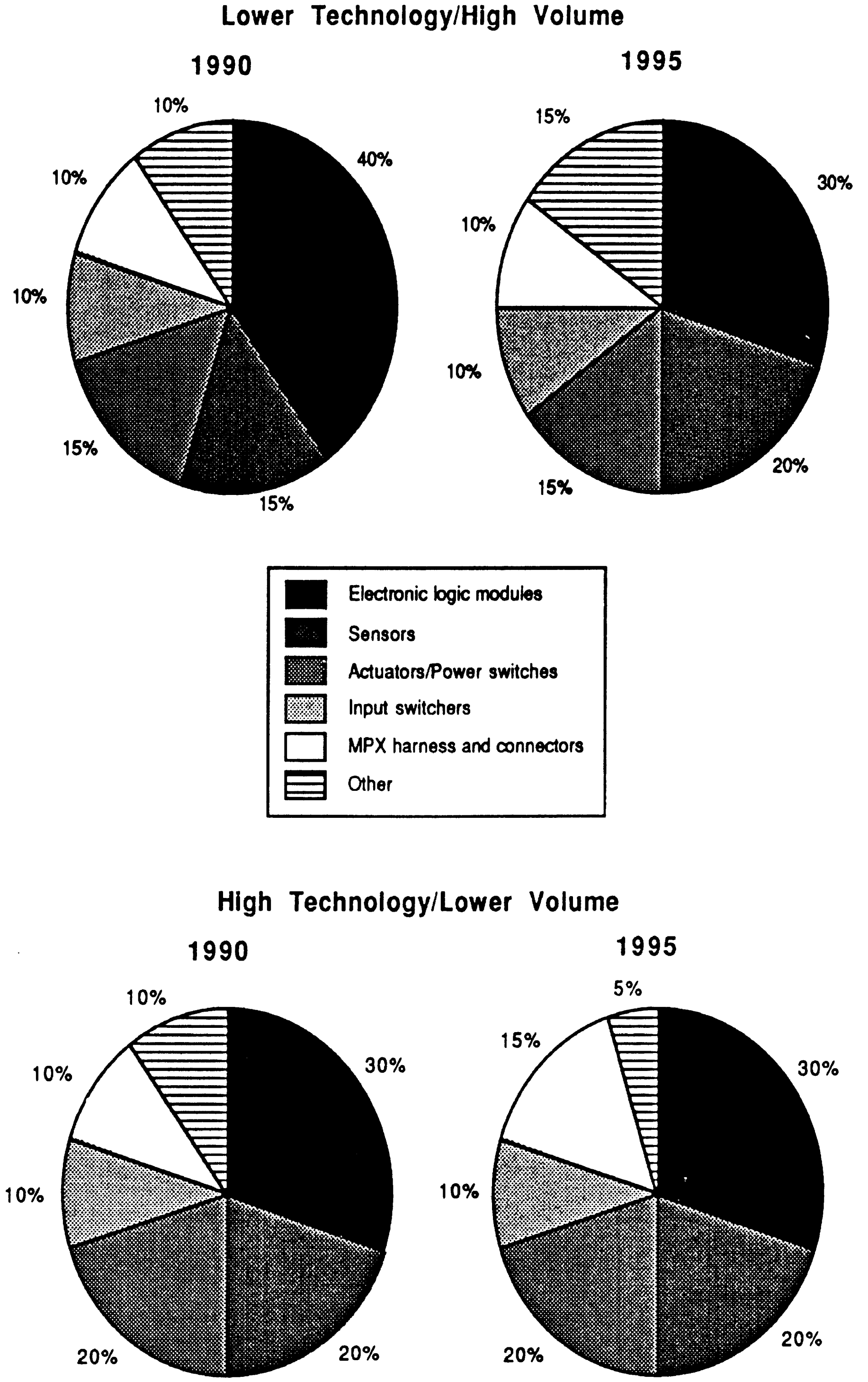

FIGURE T-9. Fraction of Electronics Costs: Vehicle System

TECH-67B. 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			
	Median Response		Interquartile Range	
Lower-Technology/High-Volume	1990	1995	1990	1995
Electronic logic modules	40%	30%	15/50%	20/45%
Sensors	15	20	10/25	15/25
Actuators/Power switches	15	15	10/25	15/25
Input switchers	10	10	5/15	10/15
MPX harness and connectors	10	10	5/15	10/20
Other	10	15		
TOTAL	100%	100%		
High-Technology/Lower-Volume				
Electronic logic modules	30	30	20/45	20/40
Sensors	20	20	15/25	15/25
Actuators/Lower switches	20	20	15/25	15/25
MPX harness and connectors	10	15	5/20	10/20
Input switchers	10	10	5/15	10/15
Other	10	5		
TOTAL	100%	100%		

Discussion

On this question the electronic componentry was broken down by component subsystems. In both the low-volume and high-volume vehicles, electronic logic modules are expected to be the most important source of cost in electronic componentry. This is followed by sensors, actuators, and power switches, and in turn, by input switches and multiplex harnesses and connectors. There is relatively little difference between the two types of vehicles. The interquartile ranges exhibited some spread, but these are deemed modest for this question.

Strategic Considerations

The response to this question suggests on a disaggregated component basis the areas of opportunity for electronic components. Those suppliers that are positioned well according to this distribution should be in a satisfactory position, assuming their level of technology and basic economics are commensurate with the market requirements. Also, it must be recognized that while this is a *forecast* of trends by experts in the field—it is not a crystal ball. It is an indicator of where the experts think trends are headed.

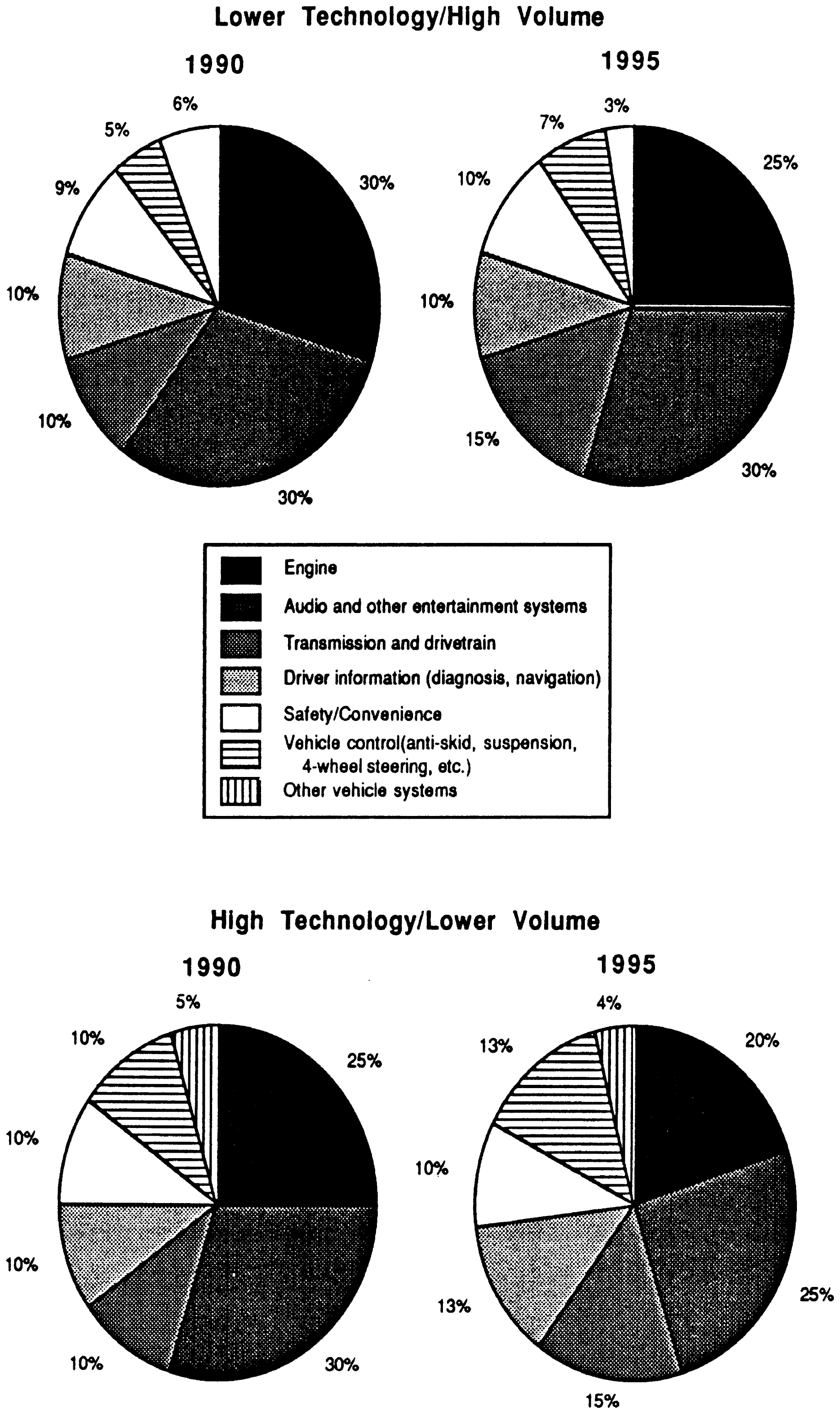

FIGURE T-10. Fraction of Electronics Costs: Electronic Components

TECH-68. What on-board vehicle systems (subassemblies and components) will be monitored by computerized electronic diagnostics by 1990 and 1995?

The following tables represent the combined responses of all three technology panels.

ON-BOARD VEHICLE SYSTEMS TO BE MONITORED BY COMPUTERIZED ELECTRONICS BY 1990

Vehicle Systems Functions and Controls	Percent of Respondents
Engine	71%
Transmission/Drivetrain	34
Braking	27
Climate/Comfort	9

The following systems individually account for 5% or less of the total responses and are rank ordered accordingly. It should be noted, however, that over 175 single suggestions for systems were presented by the panelists. Therefore, 5% or less represents a significant number of suggestions. Systems receiving fewer than three responses are tabulated under "Other Service Functions."

Fuel System Management
Body Electrical Current
Lighting
Emission Control

Instrumentation
Ignition
Suspension
Steering

Fluid Levels
Speed Control
Tire Pressure Status
Entertainment

Other Service Functions: EGR, oil pressure, brake wear, air suspension, turbocharger, defogger, door locks, airbags

Representative Responses

Once a system is controlled electronically, it will be monitored electronically
Fuel flow, fuel/air mix, throttle position
Coolant level, emission system components, brake wear, tire pressure, speed sensor, oil pressure
Trunk, inside/outside temperatures

Engine control, transmission control, automatic temperature control, cluster instrumentation, anti-skid, adaptive suspension, electronic steering, speed control
All engine and transmission variables, i.e., fluid temperatures, engine load, fuel consumption, turbo boost, ambient temperature control
Passenger comfort control systems
Lamp outage
Suspension configuration
Instrument clusters
Fuel injection, ignition, wiring, spark plugs
Only those on present data link

ON-BOARD VEHICLE SYSTEMS TO BE MONITORED BY COMPUTERIZED ELECTRONICS BY 1995

Vehicle Systems Functions and Controls	Percent of Respondents
Transmission/Drivetrain	40%
Engine/Powertrain	38
Suspension	38
Braking	36
Climate/Comfort	21

The following systems individually account for 5% or less of the total responses and are rank ordered accordingly. Systems receiving fewer than three responses are tabulated under "Other Service Functions."

Tire Pressure Status
Power Steering
Chassis Service/Maintenance

Body Electrical
Entertainment
Lighting

Power Assists
Fuel Management

Other Service Functions: navigation, speed control, driver alertness, convenience options, emission system

Representative Responses

All safety items including braking.
All major systems.
Wiper system functions.
Direction, altitude, speed, etc. for correlation to computer guidance systems.

New architecture will be developed that diagnoses every input and output. Most of hardware will be off-board but portable with data storage capability.
Multiplexed electrical load control.
Brake wear or lining condition.
Engine and transmission operating modes based on demand sequence programmed into computer for sets of conditions.
Entertainment systems (radio, disc player, etc.) and virtually all multiplexed subsystems (lighting, door locks, window lifts, mirrors, etc.).
Electrical self-correcting will begin to appear.

Discussion

Electronic-based diagnostics will permeate the vehicle and be a part of almost every subsystem with some active role. The panelist comment, *if electronics are involved, the system will be monitored electrically* is probably correct.

In many cases, systems that are already monitored electronically in some products are noted. This suggests continued growth in these areas. Also, many items could be viewed as part of a higher-order system which was also listed. For example, engines ranked very high for both 1990 and 1995. Emission control, ignition, fuel system, etc. are all part of the engine group. We have chosen to leave them separated rather than collect them within a single large system.

Clearly, the three major groups receiving the strongest support for diagnostics were powertrain (engine, transmission), chassis, and climate/comfort.

Strategic Considerations

On-board diagnostic advances suggest several interesting issues. The role of the servicing center could diminish significantly with on-board diagnostics. On the other hand, advanced or detailed diagnostics might necessitate a tie into a major service center computer system. Whichever role develops could have a profound impact on the service business.

Diagnostics might be taken to the point of prognostics where fault forecasting becomes possible. Thus the operator might be alerted to pending failure or service need based on system performance rather than fixed interval. Both factors could greatly alter the service/aftermarket business.

Redundancy or self-correction as noted in the comments should be a factor leading to far greater reliability as well.

TECH-69. Presently, the cost of sensors and actuators (switching devices) is inhibiting the application of many technologically feasible electronic advances. In what year do you expect the cost of these basic components to reach low enough levels so that they no longer represent a significant controlling factor?

	Median Response	Interquartile Range
Year of economic availability	1992	1990/1995

Selected Edited Comments

I expect sensors and actuators to remain as the controlling factors in implementation.

In a 48-volt system—the economics look much better—but still significant.

Cost reductions combined with sharing of sensor outputs by several vehicle systems.

They are the "hard" parts of electronic systems and will continue to be.

This is a matter of customer demand, competitive pressures, etc. If the customer wants them badly enough, they would not be an inhibiting factor now.

Via silicon micro-machined sensors with integrated signal conditioning.

Cost will always be a limiting factor. Appetite will expand as cost contracts.

Would suggest reliability is limiting factor.

Discussion

The panelists forecast 1992 as the year when the cost of sensors and actuators will not represent an inhibiting factor in the application of advanced electronic technologies. The interquartile range represents a reasonably good consensus regarding the year.

Discussion of Panelists' Comments

Comments suggest that cost will continue to be an inhibiting factor in the commercial development of many automotive electronic technologies.

Comparison of Vehicle Manufacturer and Supplier Panelists

The median date forecast by the two groups is identical, as is the upper interquartile range. The lower interquartile range of 1987 from the vehicle manufacturers group suggests that 25% of the OEM panel feel that the cost of electronic sensors and actuators is, at present, no longer an inhibiting factor in the application of technologically feasible electronic advances.

Strategic Considerations

A question of this type is somewhat ambiguous because, in large measure, it is dependent on the panelist's perspective. However, based on the subjective evaluation, it is evident that the impediments offered by poor economics in sensors and actuators will cease to be a significant factor in the early 1990s. We suspect that one could infer from this that reliability will also be less of a limiting factor in this time frame. The comment listed related to reliability is certainly pertinent to this issue, considering the growing importance of quality to the consumer. The value of this question is more one of indicating a general sense of direction rather than a specific point in time when this event will occur.

TECH-70. In what year will multiplex electrical systems become commercially available (30,000 + units) on U.S.-produced passenger cars?

	Median Response	Interquartile Range
Year of commercial availability for multiplex electrical systems	1990	1990/1993

Selected Edited Comments

Multiplexing will be available when cost equals savings in plant and warranty. It is not visible to car owner. Nothing in it for him.

Japanese already multiplex steering column signals. 1990 is the year for wired multiplex systems; fiber optics will follow two to three years later.

Multiplex *communications* have been in production since 1981. Load control multiplex (i.e., convenience options or lighting, etc.) is close but not cost/design effective yet.

Fully multiplexed by 1992.

When cost equals savings in plant and warranty. It is not visible to car owner.

Discussion

The panelists forecast 1990 as the year when multiplexed electrical systems will become commercially available on U.S.-produced passenger cars. The interquartile range is tight, indicating close agreement regarding the year of availability.

Discussion of Panelists' Comments

The comments of the panelists reflect the perception that multiplex systems will become commercially available only when production savings outweigh costs because there is no readily visible consumer benefit.

Comparison of Vehicle Manufacturer and Supplier Panelists

The supplier panelists forecast that multiplex electrical systems would become commercially available on U.S.-produced passenger cars in 1992, two years later than the Manufacturers Panel or the Combined Technology Panel.

Strategic Considerations

Multiplexing is certainly not a new technology; however, application to vehicles is limited at this time. Some applications already exist in some specialized vehicles (i.e., Pontiac STE steering column), but the application is still not widespread. It is also likely that multiplexing will be used in components that are transparent even to most automotive engineers. Broad application of multiplexing is ultimately dependent on a favorable total system cost/benefit analysis.

TECH-71. Which electrical/electronic subsystems will be the first to use multiplexing?

Subsystem to Use Multiplexing	Percent of Respondents
Door interfaces for power controls (power windows, seats, door locks, mirrors, etc.)	44%
Lighting controls (headlamps, tail lights, turn signals, and other interior lighting)	34
Steering column wiring	18
Entertainment	15
Vehicle information/instrument panel (IP) functions	12
Others:	
Power seats	
Computer-to-computer communications	
Emissions	
Real-time engine controls	
Ignition	

Representative Responses

Lighting will probably be the first for load control because of technology capabilities.

Cars being built with doors on in body shop, off in trim shop, and back on after IP and seat installation. Cannot have 60 strand cables going into doors.

Space and movement requirements will be a significant driver for the above systems.

Multiplexing will migrate from complex and space-restricted areas to general use as cost is reduced by increased volume.

Discussion

It is clear that door-mounted power convenience options and switches, steering column harnesses and lighting (i.e., items where signals must be distributed around the passenger compartment) are considered by the panelists to be the most likely electrical/ electronic subsystems to be multiplexed. A number of other subsystems are also forecast to be among those systems to use multiplexing.

Strategic Considerations

Areas of the vehicle with tight packaging constraints are naturally attractive to multiplexing. As customer function requirements increase it is likely that more areas of the vehicle will be subject to these constraints.

With the growing demand for quality, multiplexing reliability will be a controlling factor.

TECH-72. What percentage of U.S.-produced passenger cars will utilize multiplexing electrical systems by 1990 and 1995?

	Percent Cars With Multiplex Electrical Systems	
	Median Response	Interquartile Range
1990	5%	2/5%
1995	20	10/25

Selected Edited Comments

Already being used in Pontiac 6000 STE, Lincoln Mark VII, etc. for data transfer and diagnostics; Pontiac 6000 STE—radio, Lincoln—cruise control, lights, etc. Next, door control panels, central consoles for power accessories, i.e., door locks, mirrors, windows, seat position.

Multiplexing will be used on heavy-duty trucks first.

Need to reduce system costs of smart receivers for tracking signal—if can be done I'd see more applications.

Once the technology is introduced and integrated on a limited basis it will expand rapidly.

Reduction in cost of electronics plus increased electrical system complexity make multiplexed systems attractive.

This assumes some usage of multiplex information transmittal, not necessarily on major systems.

This still has a long way to go to replace the basic electric wiring harness. However, inroads will be made in selected harnesses such as the steering column.

Today, multiplex wiring is a cost issue. Based on 1986 economics and available technology, resulting hardware deletions and warranty improvements will not offset the cost. By 1995, it should be a cost-effective alternative. In the interim, opportunities for multiplex wiring will exist on a lesser scale (seats, steering wheel controls, computer system to computer system, and door functions).

Multiplexing will probably be used in subsystems before total car (above estimates include subsystems).

At this point, multiplexing is, typically, causing more complexity; therefore will lead into reliability problem. Probably will be introduced only on high-tech image and expensive cars.

Discussion

The Technology panelists forecast that 5% of U.S.-produced passenger cars will utilize multiplexed electrical systems by 1990 and that the incorporation of multiplexing will expand rapidly to 20% of passenger cars by 1995. The interquartile ranges indicate some uncertainty as to how rapidly or extensively multiplexing will be adapted.

Discussion of Panelists' Comments

Several of the comments touch on cost as an inhibiting factor, but appear optimistic regarding interim opportunities for multiplexing as well as the eventual resolution of the cost factor and a future expanded utilization of multiplexing.

Comparison of Vehicle Manufacturer and Supplier Panelists

A comparison of the OEM and the supplier panelists does not reveal a great difference of opinion, although the manufacturer forecasts are 2–5% less than the suppliers.

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 is twice the current Delphi IV forecast of 5% by 1990. While this may be perceived by some as a lessening of enthusiasm for multiplexing, it is of interest to note that in 1982, only 1% of the Delphi II panelists felt that multiplexing was an electronic advance likely to see broad application by 1990.

The Delphi III projection of 20% of vehicles using some multiplexing by 1992 would seem to be in reasonable accord with the present forecast of 20% by 1995.

Strategic Considerations

It can be safely assumed that multiplexing has arrived as a technology and must be considered seriously by all who interface with electrical/electronic componentry. The potential application points are highly varied as noted by panelists. One could surmise that once a "critical mass" is achieved the growth could be explosive.

TECH-73. Multiplexing can be accomplished in several ways: common bus with switching signal transmitted along a single wire to "smart" power switches; and common bus with fiber optic transmitted signals. What percentage of multiplexed systems will use these techniques or some other technology?

Multiplexing System	Median Response	Interquartile Range
Electrical Signals/ Smart Power Switches	74%	50/75
Fiber Optics	21	10/30
Other Technology Laser/infrared (IR)	5	5/15
TOTAL	100%	

The following "Other" technologies represent single responses: smart power switches but multiple 3–5 wire bus (15%); broadcast IR (5%); laser topics (10%); common mode—2 wire bus (30%). In most cases these could be viewed as subsets of the primary systems but are presented here to give an indication of expected application.

Selected Edited Comments

Natural technology advance will be: limited multiplexing in one or two assemblies such as steering column (weight and space saving), then electrical signals to reduce cost.

To enhance functionality, increase band width, and to deal with electromagnetic interference (EMI) problems, will switch to optics.

"Common bus" is not practical for automotive usage under certain failure modes.

I think this ratio may change as time goes on with increase in fiber optics usage.

Initially conventional technology will be used; smart switches will come but not by 1989/1990.

A function of time: eventually fiber optics will predominate, but I do not know how soon.

Fiber optics will tend to be in special applications where high-speed data transfer with EMI immunity are required.

Multiple buses may develop: one for control, one for micro-to-micro communications, one for audio system control, etc. Fiber optic connector price and problem of needing a "T" connector will inhibit its growth.

Jury still out.

Not economical in near future (< ten years).

Fiber optic cost will be significant factor but availability of power switching semiconductor devices will have to come faster if real progress is to be made. Even with multiplexing the power must be switched.

Discussion

Projections are that 74% of the multiplexing in passenger vehicles will be accomplished by means of electrical signals to "smart" power switches and 21% through fiber optic transmitted signals. Attention should be paid to "Other" technologies, particularly laser infrared, which received the largest number of "Other" forecasts.

The interquartile ranges are fairly tight on the upper end, indicating agreement as to capacity; however, the lower interquartile ranges, especially for electrical signals/smart power switches, reflect a degree of uncertainty.

Discussion of Panelists' Comments

The comments give insight into the special applications of fiber optics as well as some of the current problems associated with this technology. A few of the comments express the opinion that extensive multiplexing will not be economically feasible within the next few years.

Comparison of Vehicle Manufacturer and Supplier Panelists

The two groups are in agreement with respect to fiber optics application. Although the supplier panelists forecast a lower percentage for electrical/smart-power switches (60%), given the interquartile range, this is not considered a significant difference.

Strategic Considerations

As with many vehicle technologies, several options appear to be available. Developments of the interfaces in the next few years may determine the winner, although both technologies may coexist. Needless to say, developments should be closely watched.

The comment (number three) related to failure mode is extremely germane in light of customer expectations and product liability issues.

TECH-74. What percent of U.S.-produced passenger cars will use the following electronic components or systems by 1995?

	Percent Usage by 1995	
Electronic Components/Systems	Median Response	Interquartile Range
Comprehensive engine/transmission diagnostic system	50%	25/80%
Electronic/electric power steering	30	10/50
Common bus wiring	25	10/50
Fiber optic devices for control functions	20	10/30
Cathode ray tube dashboard displays	15	5/35
Laser-projected display	10	5/20
On-board map or other locational readout device	10	5/25
Voice interactive electronics	10	5/25

Other electronic components and subsystems forecast by single panelists as likely to see commercial application by 1995 are as follows with their expected level of penetration: anti-lock braking (90%); LED displays (50%); traction control (30%); brushless motors—blower/radiator (25%); liquid crystal display (10%): sonic or radar hazard avoidance systems (5%).

Discussion

The system receiving the largest percentage of panelists' forecasts for application by 1995 is comprehensive engine/transmission diagnostics. It is worth noting that engine and powertrain functions and controls were also forecast by Delphi IV panelists as the primary on-board vehicle system to be multiplexed (see Tech-68). The remaining components and subsystems listed are also forecast to occupy a significant share of the market. The interquartile ranges on many of these components and subsystems, however, are broad and suggest considerable uncertainty.

Comparison of Vehicle Manufacturer and Supplier Panelists

Significant differences between the OEM and supplier panelists are apparent in the percent application of CRT dashboard displays (OEM 5% vs. 15%) and comprehensive engine/transmission diagnostic systems (OEM 70% vs. 50%). All other electronic components or systems are within a 5% variance. See table next page.

VEHICLE MANUFACTURER COMPARED TO SUPPLIER PANELISTS

	Percent Usage by 1995			
	Median Response		Interquartile Range	
Electronic Components/Systems	OEM	Supplier	OEM	Supplier
Comprehensive engine/transmission diagnostic system	70%	50%	30/90%	25/75%
Electronic/electric power steering	20	30	10/30	15/50
Common bus wiring	25	20	15/60	10/60
Fiber optic devices for control functions	20	15	5/20	10/30
Cathode ray tube dashboard displays	5	15	5/15	5/25
Laser-projected display	5	5	1/8	3/10
On-board map or other locational readout device	5	10	5/10	5/15
Voice interactive electronics	5	10	5/10	5/20

Strategic Considerations

A broad range of key electronic-based technologies is covered in this question. The broad interquartile ranges in most technologies suggest that views are mixed. As with most survey results with broad ranges, trends should be monitored closely. Some areas are covered under separate questions.

TECH-75. What will be the three most important changes in the way cars and light trucks are manufactured between today and 1995?

The three most important changes in the way cars and light trucks are manufactured between today and 1995 forecast by the panelists are as follows:

1. Modular construction/subassemblies/parts integration
2. Automation/robotics/CIM/flexible manufacturing
3. Space-frame construction with bolt-on or adhesive-bonded panels

These three manufacturing changes collectively accounted for over 60% of the total responses. Other manufacturing changes receiving substantial support (an additional 30% of the total responses) are rank ordered as follows.

Subassembly at supplier satellite facilities
More creative labor agreements/increased employee involvement and training
Cost justification
Contiguous component manufacturing
Use of plastics and other composites
Use of adhesive bonding in place of bolts and welds

The following were also suggested as being important manufacturing changes between now and 1995.

Simultaneous engineering
Less variability/more options grouping and packaging
Fewer manufacturers/smaller manufacturing facilities
Increased manufacturer (supplier) participation in design process to improve product feasibility and reduce costs
Specialized tooling and reduced machining.

It was necessary to abbreviate the forecasts for the purpose of integrating the many responses of the panelists into comprehensive groupings. In order to provide as much insight as possible into the thoughts of the panelists, "Representative Responses" are provided in lieu of "Selected Edited Comments."

Representative Responses

Body panels painted off-line and assembled to the body at the end of the assembly line.
Modular assembly with design and validation responsibility resting with the source—I'm talking large assemblies—perhaps six to eight to the vehicle.
More integration of CAD/CAM/Replacement of Henry Ford's assembly line concept with GM10 mode (robotic moving work stations).
Simultaneous engineering of product and manufacturing process to reduce costs.

Repeatability of bodies will be improved through sizing in a single tool.

Assembly labor will decrease steadily in favor of robots and automation.

In-process verification of assembly operation—extensive use of vision systems and in-process testing. Extensive use of supplier complete modules in final assembly, i.e., fully dressed engines/ transmissions, full rear axle/brake/wheel assemblies, etc. Likely shift to modular space frame (composite material structure) and adhesive body panels (see Chrysler Liberty program, for example).

Automated paint finish inspection.

The use of plastics will increase substantially with polymeric materials replacing steel.

Feedback control of assembly process.

Flexible manufacturing systems without traditional assembly. In-line sequencing combined with real time inventory optimization.

OEM will purchase more "black box" components leading to less assembly at plants and therefore increased productivity.

Automated trim assembly.

Option grouping—minimize number of permutations.

Automatic guided vehicles will transport automobile between work stations.

Better integration between people and machines.

Computer-ordered CIM network.

Huge displacement of human labor by robotics incorporating artificial intelligence.

Increased computer process control for response to change and quality.

In-line sequencing will be the norm.

Less dedicated equipment—more programmable robots.

Material changes on body panels will change assembly methods.

Modularized subsystems will greatly reduce the number of items in the assembly plant.

More rational approach to specific technology regarding justification—methods, analysis, and applied economics.

Reduced on-line subassembling as suppliers deliver modular units.

Reduced fabrication operations due to move to plastics and forming operations.

Simultaneous assembly flow rather than through rigid single line.

Car manufacturers will move to use of subassembly sources for major components such as instrument panels, seat assemblies, etc. ... to those suppliers who will be located "next door."

Increased "beside-line" manufacture of such things as stampings.

Increased contact between suppliers and OEM producer to obtain higher quality standards.

Increased modular assembly for quality and reduced inventory.

JIT inventory with suppliers held responsible for warranty.

More methods analysis and economics in decision-making. Outsourced subassemblies in joint ventures to reduce labor rates.

Robotic installation and assembly with vision systems to control them.

Shorter production lines with multi-model plants.
Subassembly of modules which will be "glued" together—replacing many current fastener techniques.
Variety will diminish in favor of option groups to reduce necessity for flexibility in assembly plants.

Discussion

It is clear that a broad collection of changes are anticipated in vehicle manufacturing. Many of the suggested areas could be viewed as subsets of others. There is no question that a reevaluation in the automotive production process is taking place.

Strategic Considerations

The enormity of the potential change in the overall automotive manufacturing system is clear in the response to this question. In many regards, a rather fundamental change in the overall production strategy is indicated, particularly the application of advanced automation techniques and the aggressive move to the use of subassemblies or modules. Every manufacturer or supplier must track trends in this regard very closely, particularly with regard to the shifting of major responsibilities of vehicle components from the traditional assembly plant operations to the suppliers.

While many of the supplier opportunities could remain with the captive operations of the manufacturers, a change of this magnitude suggests major opportunities for the outside supplier. It would appear that we may be witnessing the formation of another and very important tier within the overall structure of the industry, namely the subsystem module tier. Together with this new tier a substantial responsibility for overall subsystem engineering will become a responsibility of all those who expect to participate in this new sector of the industry.

TECH-76. What percentage of product/design engineers and manufacturing engineers in your unit operate from a microprocessor-based workstation?

	Median Response	Interquartile Range
Product/Design Engineers	30%	20/60%
Manufacturing Engineers	15	5/25

Selected Edited Comments

Currently only outside design resources are used with CAD/CAM capabilities.

Discussion

In questions of this type, the idea of conducting multiple rounds of a survey does not apply. Each panelist is asked to reflect on computer-based workstations in his business unit. The spread is significant in that a wide range of capabilities exist. We would anticipate that the median will grow rapidly in the years ahead. If fact, some would argue that one will have to be "on line" to ensure long-range participation in the industry.

The fact that the product and design engineer is ahead of the process engineer is significant.

Comparison of Vehicle Manufacturer and Supplier Panelists

The percentages for product/design and manufacturing engineers operating from a microprocessor-based workstation supplied by the OEM panelists are 10% higher than the supplier percentages.

Strategic Considerations

The current level of use of microprocessor-based workstations in the industry is rather modest, particularly for those charged with manufacturing responsibilities. We would certainly anticipate that these percentages would grow dramatically and must be supported by extensive training of engineers and technical support staff to ensure that this new technology is used in an optimum fashion. Space-age computer-design capability is only a capability until employees can make effective use of the technology.

An important part of this process is the development of effective networks that will not only link various elements of both the product and design groups and manufacturing groups but also create connections between product and manufacturing engineers. Productivity of the engineering process must be improved dramatically to ensure long-range competitiveness, and the quality of this effort must be improved as well. The mere presence of the tools is not sufficient to ensure long-range success.

TECH-77. At the present time, what percentage of product design in the engineering unit of your organization is performed with the aid of a computer?

	Percent Product Design Computer-Aided	
	Median Response	Interquartile Range
Today	50%	20/65%
Goal by 1995	95	80/100

Selected Edited Comments

CAD is used on all new prints. By 1995 we would expect to be using CAD drawing totally.

One-hundred percent of our products are designed with *some* computer involvement, only 20% of the work is on the computer.

Discussion

Approximately 50% of the product design is presently performed with the aid of the computer currently and by 1995 this is expected to increase to nearly 95%. The interquartile ranges, particularly for today's application of computer-based design, is very broad. It should be noted that the interquartile range has a different meaning in a question of this type, because it is a measurement of a perceived indication of fact. Some organizations obviously make far greater use of the computer than others.

Discussion of Panelists Comments

The second comment highlights the difficulty of securing precise information in this area.

Comparison of Vehicle Manufacturer and Supplier Panelists

In general, the suppliers indicated that they placed less reliance today on the computer as a design tool than the manufacturers. However, the expectations of both groups were approximately the same in terms of future applications of computers.

Strategic Considerations

Obviously the computer is becoming an increasingly fundamental tool in the design process. As noted in the "Strategic Considerations" for Tech-76, it is important to understand that the availability of computers does not ensure their proper and effective use in the organizations. Significant training is required as is the development of effective methods and techniques for using computer-based technology. Effective networks must be established and the database enhanced dramatically. Furthermore, a much more systematic approach to design methodology is warranted to ensure more optimized performance. A further issue is the importance of providing support to supervisors who may not have the background to supervise younger, more computer-literate engineers.

TECH–78. In the U.S. auto industry, what percentage of product design and engineering is and will be performed domestically in the years listed? What percentage is and will be performed offshore?

	Percent Product Design and Engineering			
	Median Response		Interquartile Range	
	Domestic	Offshore	Domestic	Offshore
Today	90%	10%	80/95%	5/20%
1990	80	20	70/85	15/30
1995	75	25	65/80	20/35

Selected Edited Comments

There will be U.S. engineering centers for Japanese companies.

The current trend is for more off-shore design; government regulations may slow this trend down.

The purchase of outside engineering and the consequent loss of in-house skills and proprietary technology represents a long-term threat to U.S. manufacturers.

Discussion

The panelists suggest that, at present, 90% of product design and engineering is performed domestically. They forecast a slow, steady decline to 75% by 1995, the lost design and engineering being performed offshore. The interquartile ranges indicate a fair degree of consensus.

Discussion of Panelists Comments

The panelists suggest the general trend to offshore with the possible movement of the Japanese to U.S. sourcing of engineering. The comment with respect to the threat to the U.S. manufacturers is significant and must be carefully examined by both the manufacturer and supplier community to ensure that the proper level of engineering capability rests within their organization.

Comparison of Vehicle Manufacturer and Supplier Panelists

Although the interquartile ranges for the supplier panelists are broader than those of OEM panelists, suggesting a greater degree of uncertainty regarding this issue, the median forecasts are almost identical.

Strategic Considerations

A modest trend to offshore sourcing of engineering is indicated. We must ask, "Will this affect the ability of U.S. manufacturers and suppliers to perform cost-effective and quality engineering over the long term or do we place important elements of our business at risk with this movement?" While one would expect the offshore sourcing of some engineering to be highly probable, based on these data, it is important that centers of engineering and excellence in practically every facet of the vehicle be maintained within each major OEM if it is to be competitive. This is particularly true of highly integrated componentry.

TECH-79. What percentage of U.S. manufacturers' product design and engineering is and will be supplied by each of the following categories in the years listed?

	Percent U.S. Product Design and Engineering					
	Median Response			Interquartile Range		
	Today	1990	1995	Today	1990	1995
Internal/In-house	70%	55%	45%	50/80%	40/65%	30/50%
Suppliers (components/materials)	15	25	35	10/25	20/35	20/40
Design service supplier/consultant	15	20	20	5/20	10/30	10/30

Selected Edited Comments

Design: These services and resources may be joint ventures undertaken by vehicle manufacturers and outside (both domestic and foreign) design groups (i.e., recent Chrysler and Cadillac ventures).

I believe we'll give suppliers performance specs for large systems and expect them to deliver a finished, engineered and developed product. Design service adds a third part to the equation of confusion.

Push engineering work to the suppliers!

There is a clear trend to "gray box/black box" outsourcing design.

This response is for tool engineering only (process and design). Turnkey (suppliers' response) refers to complete supplier service (design and construction).

The purchase of outside engineering and the consequent loss of in-house skills and proprietary technology represent long-term threats to U.S. manufacturers.

Discussion

The Technology panelists forecast that, at present, 70% of product design and engineering is supplied internally/in-house. This is expected to decline to 55% in 1990 and 45% by 1995. Suppliers are forecast to take up much of the remaining design and engineering, from 15% today to 35% by 1995. Design service suppliers and consultants are expected to rise from a present percentage of 15% to 20% in 1990 and to hold steady at that percent through 1995.

The internal in-house interquartile range today is meaningless, since this is essentially a perception of a fact which can vary considerably from organization to organization. However, in the future the interquartile range has meaning and indicates that there is a rather wide range of perception of the role of both the supplier of components or materials and engineering services as a factor in the overall product engineering of the industry.

Discussion of Panelists Comments

For the most part the comments reinforce conclusions from the data that the OEMs will increasingly source out product design and engineering to the supplier segment. The last comment deserves serious consideration.

Comparison of Vehicle Manufacturer and Supplier Panelists

Vehicle manufacturer panelists consistently forecast a lower percentage for internal/in-house product design and engineering and a higher percentage for design service suppliers and consultants than did the suppliers (plus or minus 10–15%). The percentages for supplier sourcing are identical for today and 1990, with the OEMs forecasting less for the suppliers (30% vs. 40%) by 1995.

Strategic Considerations

It is evident that there is still rather substantial uncertainty with respect to the role that outsourcing plays today in the overall product design process. Some in the engineering services business believe the role of the engineering service supplier is already substantially larger than indicated by the panel. In part this may be due to the fact that it is difficult to delineate contributors to a given design process and, in fact, contribution for a given problem may come from several sectors. While the magnitude of the numbers may be suspect, one point is very clear and that is the expected growing trend to engineering outside of the major manufacturers. This is being reinforced by rather fundamental changes within the organizational structure and emphasizes engineering of powertrain and body, and overall vehicle systems and the planned outsourcing of various subassembly or module engineering. Responses suggest there will be growing opportunities for outside firms who provide services and a considerable increase in responsibility within the supplier community to add world-class engineering capability.

TECH-80. Approximately how many person hours *(direct and indirect*)* are now required for production within the following categories and what will it be in the years listed: (1) U.S.-owned and -produced passenger cars, excluding joint ventures and (2) Japanese cars produced in Japan.

Number Person-Hours Required for Production

	Median Response		Interquartile Range	
	U.S.	Japanese	U.S.	Japanese
Today	150	100	100/200	70/100
1990	120	95	80/180	65/150
1995	100	80	70/150	55/135

*Include the vehicle manufacturers and their parts, component, and materials suppliers.

Selected Edited Comments

I think the difference between the U.S. and Japan today is more where the work is done rather than total person-hours. I think in Japan a greater amount is done by suppliers and less by OEMs.

It should be pointed out that the difference in production hours required for U.S. cars vs. Japanese cars is not necessarily due to differences in levels of skill or productivity of the respective workers. It obviously takes longer to produce larger luxury cars than smaller Japanese models. In addition, other factors, such as labor costs, dictate various mixes of man and machine to achieve an optimal return on investment.

Supplier companies will move much slower "as a group" than car manufacturers.

If we don't get a big part of the problem solved by 1990, our hours by 1995 will be zero because we won't be in business. It requires no great, long lead time, design or processing changes. It's just a matter of getting the slack out and then going to work. Labor costs are the problem; "chased" far enough upstream most costs are labor.

Discussion

Panelists' responses estimate that, at the present time approximately 150 person hours are required for the production of U.S. passenger cars. In Japan 100 hours are required. The number is forecast to decrease to 120 person hours in the U.S. vs. 95 for the Japanese in 1990 and to decrease further to 100 hours for the U.S. vs. 80 hours for Japan by 1995.

The interquartile ranges are very large, indicating considerable disagreement, or lack of knowledge, as to the actual hours required. What is clear, however, is that the number of U.S. person-hours is expected to gradually decline, but so also are the number of Japanese. The U.S. rate of reduction will be far greater than in Japan. The last comment is particularly noteworthy.

Discussion of Panelists Comments

The comments presented are very pertinent to a thoughtful analysis of the person-hour differential between U.S.-produced and Japanese-produced passenger cars.

Comparison of Vehicle Manufacturer and Supplier Panelists

The number of person hours required for the production of U.S.-produced and Japanese-produced passenger cars forecast by each group are essentially the same through 1990. By the year 1995, however, the OEM segment forecast a number of person hours for both U.S.- and Japanese-produced vehicles slightly higher than the combined median (100 U.S. vs. 95 Japan). The interquartile range for both manufacturers and suppliers is at least as broad, if not broader, than the combined interquartile range.

Strategic Considerations

When we asked this question we did not anticipate that panelists would know precisely the number of hours required to produce vehicles both in the U.S. and Japan. In fact, in many regards we believe that this number may not be knowable because of a lack of a truly accurate cost accounting system both in the U.S. and Japan. However, perceptions are valuable indicators of this number and, therefore, merit careful consideration. The comment stated in the edited comments (that ultimately every cost is essentially labor) is obviously pertinent to a comprehensive analysis.

Clearly, it is anticipated that the U.S. will gain ground on the Japanese, which could be expected, considering the learning curve of both industries. For one who is closer to zero, each incremental gain becomes much more difficult than for one who is further away. We are heartened by the rather dramatic progress expected in U.S. productivity. However, one must be fully aware of the down side of this, in that this represents a major potential for disemployment from the automotive industry and, therefore, could create enormous social pressures within the economy. In fact, these pressures may become substantial enough to become a major national issue in the years ahead.

TECH-81. Popular opinion suggests that statistical process control (SPC) is widely used in the automotive industry. In existing manufacturing processes with which you are familiar, what approximate percentage of the OEMs and suppliers are actually utilizing SPC in the manner indicated?

	Median Response		Interquartile Range	
	OEMs	Suppliers	OEMs	Suppliers
Used Properly	50%	50%	40/60%	37/60%
Misused	20	20	10/25	10/25
Not used	30	30	20/30	20/40

Selected Edited Comments

OEMs are pressuring suppliers to use SPC techniques that they are not using themselves.

It is a sad comment that our major suppliers are ahead of the OEMs.

The OEMs have less understanding of statistical methods than suppliers and don't realize it.

Unfortunately most of SPC is used to develop charts for show-and-tell purposes and are superficial in nature. It will be very effective if and when feedback systems start controlling the process (much like we find in chemical plant and other continuous process-controlled manufacturing).

Discussion

The panelists estimate that 50% of the OEMs and 50% of the suppliers use statistical process control properly, 30% of both groups do not use SPC, and 20% are not viewed as using it properly. The interquartile ranges indicate a relatively broad spread, particularly on a percentage basis. The interquartile range has a different meaning in this question, in that it is a perception of fact.

Discussion of Panelists Comments

An examination of the data presented as well as a comparison of the OEM and supplier responses would seem to mitigate several of the comments.

Comparison of Vehicle Manufacturer and Supplier Panelists

The responses for all three parameters of SPC usage are essentially identical.

Strategic Considerations

It is evident from the results that while statistical process control is important to the development of effective high-quality manufacturing, it still is in a growing phase. One would suspect that the progress will be rapid toward applying SPC in the future, whereas with the Japanese it has become a given in the basic formulation of a production system. With the enormous pressures on product quality today, the driving force is to implement mechanisms to ensure the quality of both components and finished vehicles. Any manufacturer or supplier that cannot meet the growing quality expectations will have a very difficult time being competitive in the years ahead. Inherent in an effective quality strategy is the necessity to prevent problems at each stage in the process by ensuring that every process is under control.

TECH-82. The U.S. industry is moving in the direction of correcting quality control problems as they occur *in production*, rather than at the end of the assembly line. One measure of this change is the declining use of repair areas at the end of the U.S. assembly lines. For a U.S. final assembly line operating at a rate of 60 cars per hour, what is the present and planned size of the end-of-line repair areas, measured in vehicle units.

	Vehicle Units: Capacity per Repair Area	
	Median Response	Interquartile Range
Present	50	20/60
1990	20	10/20
1995	10	0/12

Selected Edited Comments

Repair bays are not a good indicator. Better indicator is repairs in system vs. repair after assembly.

I believe they are shipping uncorrected quality—not correcting it—especially fit and finish.

Plants will begin to ship vehicles that need repair if capacity of repair areas is filled. This trend is definitely declining and should be eliminated shortly.

Discussion

Vehicle capacity of end-of-line repair areas is forecast to decline from an estimated 50-unit capacity to a forecast 20-unit capacity in 1990 and decrease further to 10 units by 1995.

The interquartile ranges for 1990 and 1995 are very good on the upper quartile but broader on the low end. This is particularly noticeable with regard to the "Present" capacity estimate. This lack of consensus may reflect differing manufacturing systems in different facilities, rather than a lack of knowledge of present circumstances.

Discussion of Panelists' Comments

The first comment is important but quantification may be difficult. The other comments suggest that the pressure to move the product "out the door" are still immense.

Comparison of Vehicle Manufacturer and Supplier Responses

The supplier panelist projections are 20% to 40% less than the manufacturers through 1990. The forecasts for 1995, however, are identical.

Strategic Considerations

It is evident that there is a major trend to reduce the end-of-line repair capacity in plants. While this is a very rudimentary measure of quality control, it still is an indicator and the clear expectation is for better process control in the production system. Personally, we believe that with the competitive pressures developing, that successful manufacturers in the middle 1990s will be producing almost perfect vehicles and, therefore, need very limited space for end-of-line repair. It is absolutely essential to develop sufficient discipline in the overall production system to ensure that world-class quality goods are manufactured at every stage of the system.

TECH-83. With changing concepts of assembly, what subassemblies or modules are likely to be produced "on-line" or "off-line" (i.e., away from vehicle assembly lines) in advanced design plants by 1995.

Subassemblies: On-Line by 1995	Percent of Total Responses
Body/frame/platform	100%
Engine/powertrain	7
Exterior parts/trim	7
Doors	7
Steering column assemblies	4

Others:
- Brakes
- Fuel lines
- Tanks
- Evaporate control systems
- A/C systems
- OEM-supplied subassemblies (e.g., weldments)
- Module with steering and shaft

Subassemblies or Modules: Off-Line by 1995	
Instrument panels	76%
Power plant assemblies and dress-up	44
Front and rear suspensions	37
Seating modules	27
Door assemblies	22
Transmission/drivetrain	22
HVAC modules	17
Floor-mounted interior consoles	15
Steering column assemblies	10
Brake assemblies	5
Axles	5

Others:
- Underbody
- Radiator
- Fan
- Front sub-frame
- Bumpers
- Induction systems
- Exhaust systems
- Steering systems
- Power accessory systems
- Passive restraint systems
- Fire wall assembly
- Wheel end corner assemblies
- Deck lid
- Hood

Representative Responses

ON-LINE
Modified space frames
Body module (front) with powertrain
Body stampings
Rear modules
Engine bodies
Body minus fire wall, doors, hood, deck lid
Space frames

OFF-LINE
All but body
Some frame–chassis
HVAC as an assembly
Clutch brake assembly
Floor-mounted console with transmission selector and parking brake
Power packs
Front of dash assemblies
Engine dress

Discussion

The issue of modular construction or the use of "on final assembly line" or "off final assembly line" construction practices is one of the most important issues influencing automotive production. Continued strong support is seen for the basic body/frame/platform construction on-line and rather limited support for such areas as the engine, powertrain, exterior parts, doors, etc. There is generally a much higher level of expectation for the use of off-line subassemblies, or modules, with strongest support for instrument panels, power plant assemblies, front and rear suspensions, door assemblies, and seating modules.

Strategic Considerations

Very fundamental changes in the traditional automotive assembly line are suggested, the most general being the replacement of many of the traditional tasks performed "on-line" with module construction. This certainly creates a major opportunity for suppliers as the industry is re-tiered with the emergence of a major new layer or expansion of the existing first tier. The module supply opportunity will create significant challenges for the traditional manufacturers' in-house supplier as well as for the non-OEM supplier. We would surmise that this trend will spawn a host of very creative associations and joint ventures between complementary suppliers.

This trend also would suggest a threat for the supplier who presently is at a high tier in the supply structure that might fall to a lower position, that is, feeding a module supplier rather than the OEM directly. The role of the transplant supplier in this area also warrants careful consideration. All in all, we generally believe that the general shifting and restructuring spawned by the trend towards the use of off-line subassemblies is one of the most challenging developments currently occurring in the industry.

TECH-84. What percent (dollar value) of "off-line" vehicle subassemblies or modules (excluding engines and transmissions) will be produced by the OEMs and what percent by suppliers?

	Percent "Off-Line" Vehicle Subassemblies/Modules			
	Median Response		Interquartile Range	
Produced by:	1990	1995	1990	1995
OEMs	65%	50%	60/70%	50/55%
Suppliers	35	50	30/40	45/50

Selected Edited Comments

Some of the suppliers could be OEM.

Discussion

When asked what percentage of "off-line" vehicle subassemblies will be produced by the vehicle manufacturers or by suppliers, the panelists forecast that in 1990 the ratio will be 65% manufacturers and 35% suppliers; by 1995 this ratio is expected to be 50:50. The interquartile ranges are very close, indicating a very good consensus for the ratios presented.

Comparison of Vehicle Manufacturer and Supplier Panelists

There is no significant disagreement between the ratios forecast by the OEM and supplier panelists.

Trend from Previous Delphi Surveys

In 1983, the Delphi panelists projected that the dollar value percent of "off-line" subassemblies would be split 50:50 between manufacturers and suppliers in 1987, 1990, and 1992. Delphi IV panelists do not expect this 50:50 ratio until 1995.

Strategic Considerations

A very significant increase in opportunity for the supplier community is expected as component subsystems are sourced outside of the OEM family. As noted in the prior question, this creates a major new opportunity but also a host of serious challenges. This trend will clearly demand careful attention on the part of the supplier community, particularly those who expect to participate as a tier-one supplier. This clearly creates an opportunity for creative thinking.

TECH-85. On the average, by 1990, what will be the interval in years between basic passenger car platform redesign?

	Basic Passenger Car Platform Redesign	
	Median Response	Interquartile Range
Interval in Years	5	5/8

Selected Edited Comments

The timing used to be eight years, but more manufacturers provide a greater frequency of new products to the marketplace, producing shorter intervals.

Four years for the Japanese; five to six years for U.S. OEMs; six to eight years in Europe.

Discussion

By the year 1990 the interval in years between basic U.S.-produced passenger car platform redesign is forecast to be five years. The interquartile range indicates a fair degree of consensus among the panelists on this topic.

Comparison of Vehicle Manufacturer and Supplier Panelists

Median responses are identical at five years.

Strategic Considerations

While the responses to this question suggest that five years is likely between basic platform changes, it is very difficult in many respects to define what is meant by a platform, since increasingly a number of vehicles with modified platforms are typically derived from the "same" platform. Market pressures are obviously going to be an important factor, as are cost and quality considerations. If the market continues to increase its almost insatiable demand for newness and variety in the product, this could shorten various product life cycles while, at the same time, cost pressures suggest trying to increase these cycles. It would appear that the manufacturers may face a classic dilemma which could give rise to technology that would permit rather inexpensive product differentiation. We suspect that the industry will be severely challenged on this issue.

There is a definite trend by each vehicle manufacturer to consolidate numerous platforms, drivetrains, and suspension components into a few system packages that can be used with a variety of body styles and configurations and thus targeted to a variety of markets. The goal will be to spread the cost of the heavily capitalized drivetrain and stamping facilities over as many units as possible. Cost savings within this area can then be applied to providing more frequent body and trim updates to keep vehicles competitive with new imported vehicles and within new customer niches as they appear. Within this environment, the flexibility and ability of suppliers to meet cost, quality, and product objectives will be paramount.

Lead time is obviously a critical issue. Generally U.S. manufacturers must shorten it substantially. Once the major and very expensive engine redesigns are brought on stream in the next five to ten years, funding for shortened model change intervals will be possible.

TECH-86. *The following is a two-part question.*

TECH-86A. If there is no domestic content legislation for the U.S., what percentage of parts, components, subassemblies, etc., purchased (dollar volume basis) by *domestic U.S.-owned vehicle manufacturers* will be sourced outside the U.S. in the years 1990 and 1995?

	Median Response		Interquartile Range	
Outside Parts Source	1990	1995	1990	1995
Japan	10%	10%	5/15%	6/15%
Korea and other Asia	5	10	2/10	8/20
Mexico and South America	5	9	5/10	5/15
Canada	5	7	5/10	5/10
Western Europe	5	5	2/5	2/5
TOTAL	30%	41%		

MEDIAN FORECASTS FROM FOUR DELPHI SURVEYS
1990 PARTS SOURCING OUTSIDE U.S.
BY U.S. VEHICLE MANUFACTURERS

	Forecast for 1990 at the Time of the Survey			
Outside Parts Source	1979 Delphi I	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Canada	N.A.	9%	8%	5%
Western Europe	N.A.	4	4	5
Japan	N.A.	8	9	10
Korea and Other Asia	N.A.	4	3	5
Mexico and South America	N.A.	8	6	5
Others	N.A.	4	0	0
TOTAL	15%	37%	30%	30%

Selected Edited Comments

Currency values have a dynamic impact on these estimates.

The majors will source so much outside that this is an impossible question.

I am including in the foreign sourcing the 40-50% of U.S.-owned vehicle manufacturers' products which will be imported built-up, i.e., around 100% foreign content.

Much depends on political stability and local content legislation.

The trend to more offshore sourcing is clear; degree is the question.

Discussion

Technology panel forecasts indicate an expectation that the proportion of parts purchased from outside the U.S. for use in manufacturing or assembling vehicles within the U.S. will rise significantly from 30% in 1990 to 47% in 1995. The interquartile ranges are broad enough to suggest considerable uncertainty regarding the median. This is an important consideration, particularly in the upper quartile range, where the data for Asian and Latin source countries indicate that 25% of the panelists expect these percentages to be at least twice that of the median for both 1990 and 1995.

The most dramatic increases are forecast to be from Korea and other Asia, and from Mexico and South America, where the percentage of parts sourced in 1995 is expected to double from 1990.

Discussion of Panelists' Comments

The comments of the panelists reflect the widely held opinions that the actual percentages are very much dependent on political factors, e.g., relative currency values and domestic content legislation.

Comparison of Vehicle Manufacturer and Supplier Panelists

On an aggregate basis, forecasts of the OEM panelists forecast less offshore sourcing than suppliers. Manufacturers forecast a total percentage of offshore parts sourced to be 26% in 1990 and 40% in 1995; whereas the supplier panelists expect 40% and 50% outsourced, respectively, in the years indicated. Suppliers forecast a 10% share for Canada in 1990, dropping to 8% in 1995.

For Korea and other Asia, manufacturers forecast 2% in 1990. For Mexico and South America, suppliers forecast 10% in 1990 and manufacturers 5% in 1995.

Trend from Previous Delphi Surveys: 1990 Forecast

In forecasts for 1990, the three previous Delphis indicate a gradual upward adjusting of the Japanese percentage to a leveling off at 10% in 1990. With regard to Korea and other Asia and to Mexico and South America, while there appears some moderation of earlier expectations expressed in Delphi II, it is clear from the 1990–1995 data that the panelists expect continued growth in these countries, particularly in the period between 1990 and 1995.

Strategic Considerations

Continuing trends from previous Delphis, both manufacturers and suppliers expect increased sourcing of components outside of the United States. While the trend is to think offshore, as noted in the comments, there are some major factors that could alter this expectation, including domestic content legislation or other political pressures and shifts in expectations for exchange rate. While the question was stated to diminish the domestic content factor, there is no doubt that the exchange rate issue is of great significance. Today, with the considerable strengthening of both the Japanese yen and German mark, the sourcing of components in those areas becomes much more expensive.

Another key factor is the likely role that the non-traditional U.S. supplier will play, such as the Japanese transplant, increasingly locating facilities in the United States. We would suspect that an appropriate global strategy will be one that will provide some flexibility in terms of sourcing, so that the variations in exchange rate or other factors do not cause fundamental competitive problems. Obviously any strategy for either the manufacturer or supplier is fundamentally entwined with global considerations.

TECH-86B. If there is no domestic content legislation for the U.S., what percent of parts, components, subassemblies, etc., purchased (dollar volume basis) by *U.S.-based but foreign-owned vehicle manufacturers* (VWoA, Toyota, Nissan, Honda, Mazda, Mitsubishi) will be sourced within the U.S./Canada and what percent will be sourced outside the U.S.?

	Median Response		Interquartile Range	
Parts Source	1990	1995	1990	1995
U.S./Canada	30%	30%	15/40%	25/50%
Internationally Sourced	70	70	60/80	50/75

Selected Edited Comments

Japanese appear determined to source to Japanese companies, whether domestic or overseas.

Weakening dollar will moderate slightly.

Economic considerations will force domestic manufacturers to go off-shore to low labor cost sources as a matter of survival.

If no domestic content legislation or foreign trade pressure, off-shore competitors will import built-up units.

Discussion

It is clear from the responses that, in the absence of domestic content legislation, the panelists expect the ratio of parts sourced by U.S.-based but foreign-owned vehicle manufacturers to be 30% U.S./Canada and 70% international. This distribution is expected to prevail through 1995. The interquartile ranges are reasonably close. The upper interquartile range for U.S./Canada, however, would seem to provide a small degree of latitude for optimism on the part of U.S. and Canadian suppliers.

Discussion of Panelists' Comments

The comments of the panelists address a few of the underlying motivations for foreign-owned OEMs to move off-shore for parts, components, and subassemblies.

Comparison of Vehicle Manufacturer and Supplier Panelists

The responses of OEM and supplier panelists are in close agreement.

Comparison of Replies to MKT-24B

The Marketing panelists expect transplant sourcing will be 35% domestic in 1990 and 40% in 1995. This is in contrast to the Technology panel, which does not anticipate any deviation from the current estimate of 30% domestic and 70% international through 1995.

Strategic Considerations

Panelists are not very optimistic about significant growth in sourcing on the part of foreign manufacturers in the United States and Canada. However, we would certainly anticipate that this could be altered rather dramatically as more transplant suppliers locate in the United States and if the yen and mark continue to strengthen. Also, based on numerous personal contacts with foreign manufacturers, they expect to increasingly develop relationships with U.S. suppliers and move more aggressively with U.S. sourcing. In particular with the Japanese it must be remembered that a sourcing relationship will develop only after a general relationship is established and there is rather significant confidence on the part of the manufacturer regarding the total capability of the supplier.

The key message in dealing with the Japanese is patience and perseverance and, of course, cost and quality. Relationships must be carefully nurtured.

TECH-87. What major vehicle component parts and materials are candidates for high-volume, off-shore sourcing? What are the most likely countries from which these components and materials will be sourced?

Components

Off-Shore Components	Percent of Respondents for Each Variable
Electrical/Electronic Components	70%
Engines	64
Transmissions	42

Other off-shore components with lesser percentages are: pistons, brakes, radios, lamps, instrument panels, electric motors, generators and switches, plastic components, rubber parts, heavy-duty vehicle components, wiring harnesses, axles, climate controls, bearings, suspensions, hardware assemblies.

Within these groups, the source country breakdown is as follows:

Electrical/Electronic = 70%

Source Country:	
Japan	40%
Korea	34
Other Asia*	14
Taiwan	6
Germany	2
Other Europe	2
Mexico	2

Engines = 64%

Source Country:	
Japan	45%
Mexico	23
Brazil	15
Korea	7
Germany	4
Other Asia*	4
Canada	2

Transmissions = 42%

Source Country:	
Japan	49%
Korea	16
Mexico	11
Brazil	11
Germany	5
Other Asia*	5
Canada	3

Others: <4%

Component	Source Country
Brake assemblies	Mexico, Brazil, Korea, Australia
Wiring harnesses	Mexico, Taiwan, South America
Bodies/chassis	Germany, Italy
Axles	Korea, South America
Generators	Japan, Korea, Other Asia
Climate controls	Japan, Korea, Mexico
Bearings	Japan
Lamps	Japan, Germany, Italy
Suspension components	Japan, Korea, Mexico, Europe
Cylinder heads	Europe
Wheels	Europe
Camshafts	Europe
Hardware assemblies	Korea
Cast iron block heads	Brazil
Sheet metal fenders	Korea
Machined parts	Korea, Taiwan
Pistons	Brazil, Mexico
Radios	Korea, China
Instrument panels	Korea
Electric motors	Europe, Asia, South America
Plastic components	Taiwan, Korea
Heavy-duty engine components	Brazil
Rubber parts	Taiwan, Korea
Stamping dies	Spain, Belgium, Japan

*Other Asia includes Malaysia, Singapore, China, etc.

Materials

Of major vehicle materials considered likely candidates for high-volume off-shore sourcing, the leading candidates were:

Off-Shore Materials	Percent of Respondents for Each Variable
Steel	81%
Castings	16
Aluminum	13
Ceramics	6
Glass	6
Rubber	6
*Others	6

*Other off-shore materials with lesser percentages are: textiles, plastics.

Within these groups, the source country breakdown is as follows:

Off-shore Materials	Percent of Total Responses for Each Variable
Steel = 81%	
Japan	52%
Korea	22
Europe	15
Brazil	7
China	4
Castings = 16%	
Brazil	40%
Mexico	20
Germany	20
Japan	20
Aluminum = 13%	
Brazil	40%
Canada	20
Russia	20
Australia	20

Others = 6%

Off-Shore Material	Source Country
Glass	Korea, China, Europe
Ceramics	Japan
Rubber	Japan, Korea
Textiles	Asia
Plastics	Europe

Selected Edited Comments

Moving to better economic utilization of plants and more segmentation will move manufacturers to joint-venture capital intensive parts (e.g., engines).

Discussion

This question provides valuable insight into the components and materials that are believed to be likely candidates for off-shore sourcing and their probable source countries. That the most likely candidates are electrical/electronics, engine, and transmission components should come as no surprise. What is of considerable interest is the long list of other components that have been forecast by the panelists to also be likely candidates for off-shore sourcing. That list touches on almost every conceivable component of the automobile.

With regard to materials, the fact that 81% of the panelists who responded to this question consider steel to be the most likely off-shore sourced material should initiate reflection on the future of the domestic steel industry and its historically close relationship with the automotive industry.

Comparison of Replies to MKT-26

In terms of rank-ordered percentages the Technology panelists considered electrical/ electronic components to be the primary off-shore sourced component, whereas the Marketing panelists gave the largest response to engines. From an overall perspective, however, the Technology and Marketing panelists are in close agreement for both components and materials.

Strategic Considerations

The world auto-parts-sourcing is indeed complex and will probably become even more so because of exchange rate volatility, political factors, and most importantly, the increasing ability of domestic parts manufacturers to complete. We suspect that ultimately almost every auto-producing nation will participate in the industry as if they had local content requirements, i.e., a major fraction of total automotive value will be produced in each nation. This does not suggest that every nation will produce every part but perhaps those where comparative advantage is enjoyed. A reasonable balance or equity may be necessary to preserve an orderly trade relationship.

TECH-88. Just-in-time (JIT) reduces inventory costs; but perhaps its greatest value is that it enforces higher standards of quality and overall manufacturing discipline. Some do not seem to understand the quality concept and speak of meeting JIT requirements through warehousing. How widespread is this misunderstanding and what can be done to correct it? Please comment.

	Percent of Total Responses
Nature of JIT Misunderstanding is Widespread	67%
Nature of JIT Misunderstanding is Not Widespread	28
Neutral Opinion	5

Discussion

It is clear that a substantial majority of the panelists feel that "just-in-time" is a widely misunderstood concept. Within the majority group the distribution was 40% vehicle manufacturer panelists, and 60% supplier panelists. Similarly, within this majority group, over 40% felt that JIT was understood as switching the warehouse and quality responsibility from the OEM to the supplier. Also, approximately 50% of the panelists within this group felt that education, training, and experience would help to alleviate the misunderstanding. The opinion that a misunderstanding of JIT was not widespread was distributed almost equally among OEM and supplier panelists. This is a question where the comments or responses are an integral part of the analysis. Therefore, "Representative Responses" are categorized as follows: *Misunderstanding of JIT is Widespread*, and *Misunderstanding of JIT is **Not** Widespread.*

Representative Responses

MISUNDERSTANDING OF JIT IS WIDESPREAD

Appears to be quite widespread; correction requires on-line material scheduling and controls on inventory costs.

Each level of supply has to adopt a commitment to JIT, for example: tape used by assembly plant, tape manufacturer and supplier of raw materials to tape manufacturer—need better planning and more open sharing of volumes and projections in future.

Just-in-time requires firm schedules. Until they are obtained, the warehousing requirement is there in actuality. Most suppliers understanding JIT as a potential system for in-process savings, too many components are not of a proper quality level for full JIT implementation, even with firm schedules.

JIT has moved the warehouse to the supplier. It is an OEM cost-cutting system. Quality can be improved by process but JIT is not responsible for the quality improvement.

Less than 50% understand the real value—change the name to "in-line," "continuous," or "flow-through" manufacturing.

Little consideration of JIT as a factor in improving quality is given. Among suppliers the warehousing idea is often expressed and the entire concept of JIT is viewed as an attempt by the OEMs to move outside the warehousing costs and tied up capital. This feeling is widespread.

Misconceptions are more widespread at the OEM than at progressive suppliers. Training will correct.

Misunderstanding is very widespread. OEMs must insist that an acceptable JIT program be more than a nearby warehouse.

Misunderstanding is very widespread. Management understanding and direction can correct.

Nature of misunderstanding unknown. Solution would be to educate suppliers who are involved with their customers in JIT as to potential positive bottom line effect if warehouse "crutch" is not used, while stressing negative impacts (wasted dollars, lower quality standards, and less than ideal manufacturing discipline). Warehousing and inventorying allows inspecting out bad parts after final manufacture rather than correcting during the process at the flawed station.

OEs speak with forked tongue regarding JIT. They want it but won't accept or implement discipline to hold forecast production schedules to make it happen. They hold supplier accountable for meeting changes. Hence warehousing.

Quite widely spread. The common belief is that the suppliers will absorb warehousing cost. To correct this, more "education" and information is needed. A seminar sponsored by SAE or ESD would be appropriate, otherwise hard experience will be the ultimate teachers.

Smaller and second-tier suppliers perceive JIT as a means of shifting inventory costs by OEMs. The OEMs must work through primary suppliers to force the discipline through the supplier chain.

It should be stressed that just-in-time puts the entire quality of the product we receive on the back of the supplier.

There is a belief that JIT by the first tier of Japanese manufacturers is really a program whereby the inventory has been pushed down to the second- and third-tier suppliers.

The term is widely misunderstood. The terminology should be changed to be more comprehensive and descriptive.

Quite misunderstood. The best way to correct the misunderstanding is to implement case-by-case JIT. Only then can all the benefits associated with JIT be seen and understood (i.e., seeing is believing).

Very widespread, and I'm not sure it's a "misunderstanding" between U.S. suppliers and U.S. OEMs. Financial benefits of warehousing (at suppliers' expense) can be significant to OEMs.

Very widespread—the U.S.A. copies without evaluating how to adopt an oriental operating technique into an occidental culture. Need factual data on various benefits of JIT.

We have spent 100 years teaching manufacturing people that large banks are necessary insurance; it will take some time. Additionally, we are structured to make large-cycle runs with our equipment and tooling.

JIT in the true Japanese concept requires that supplier manufacturing facility be located near enough to user to permit small "JIT" quantity shipment to be made without building a duplicate manufacturing plant near users. Local warehousing is a next best alternative—quality concept and warehousing not mutually exclusive concept—rather a U.S. variation based on inherent greater distance between supplier and user plants.

Many small and marginal suppliers do not understand. Teams may have to go into these operations and give specific details on JIT use and implementation.

Misunderstanding is significant. There should be training and education through the second-tier supplier.

Much misunderstood today. A whole new industry of "slush" warehousing is underway.

Process capabilities are not fully developed/understood before JIT implementation. Therefore, even if flows are set up, the need for "warehousing" remains.

Although this problem exists, more importantly some suppliers do not supply parts to link with JIT requirements, necessitating premium freight. This distorts the supply sourcing decision if a low cost source is unreliable and requires premium freight.

Auto industry is shoving the cost reduction of low inventories down the supply line with little regard for the quality issue involved. Inventory goals shall be obtained regardless of process capability.

I believe it is misunderstood by (1) people dissociated from manufacturing, (2) people dissociated quality and scheduling, (3) corporate management that is too far removed from product costing.

JIT is widely misunderstood; currently available training, continued technical discussion through trade journals, etc., should alleviate this misunderstanding.

Use of warehousing is a common approach to JIT—it will require a long time and many never reach success in fully correcting it! Even in Japan, JIT is more often "served" by warehousing—especially by parts suppliers.

I believe the use of a "half-step" commitment to JIT results from manufacturing sites unwilling to make full commitment. About 50% fall in this category.

JIT is not used as much as it is believed to be. Has problems for complex components due to large variation in customer demand.

Seems to be very widespread. This is partially because the manufacturers are talking about geographic proximity to assembly plants and not stressing the concept of JIT manufacturing.

Very widespread—true JIT requires us to redo and rethink our manufacturing systems—which will take years.

*MISUNDERSTANDING OF JIT IS **NOT** WIDESPREAD*

As far as I am concerned it is not widespread. All contacts we have with our customers understand that warehousing inventory to comply with JIT requirements defeat its purpose, and that the value of JIT extends well beyond inventory cost reductions.

It is not really misunderstood in the major U.S. auto industry; the problem is complexity, regarding number of options that can be ordered and built. Solution: reduce the number of free-standing options.

Most U.S. companies do not have the quality capability to make JIT work. They understand the concept but do not provide resources to improve quality sufficiently.

This was a misconception some years ago while the process of JIT was being initiated. Manufacturers and suppliers are now aware of advantages at all steps of process from raw material through final assembly. Continued educational programs and the presence of "enlightened champions" still help.

The concept of JIT is well understood, but not adequately evaluated yet.

Quality concept is well known and new plants are being planned now to take advantage of accepting only quality parts at assembly line or shutting it down.

Quite knowledgeable now, but JIT requires quality upgrading of manufacturing line as well as product.

I believe that 95% of the auto industry now understands JIT especially in terms of reduced inventory cost. The most effective way of correcting any remaining misunderstanding is to employ JIT and demonstrate the quality and manufacturing discipline benefits.

I do not think there is much misunderstanding but supplier with offshore manufacturing facilities must inventory to protect customer from unforeseen delays (air freight, shipping, trading, etc.).

I don't feel it is very widespread. Cost pressures will to some extent correct the problem. However, with suppliers from overseas who manufacture overseas, warehousing may still be required close to the OEM.

I think most people understand that just-in-time is no inventory, high quality, and stable schedule.

Everyone wants and understands JIT for their own internal production—big users think JIT is how vendors are to deliver parts thus warehousing (at vendor expense).

JIT is not misunderstood. But raw material inventory has to be in place at the manufacturer. The OEM benefits the most from no inventory and placing the burden on the supplier for inventory. Quality must be mandatory when there is no inventory and demand increases.

Most OEM and first-tier supplier companies properly understand JIT as a manufacturing system. Identifying, quantifying, and implementing specific JIT actions is more difficult. Experience and training are the answers.

The misunderstanding is not as widespread as implied by the question. JIT requires short supply lines and also long-term supply contracts, so that suppliers will invest in "nearby" production capacity. Much progress is being made, but suppliers who fled from the UAW to the Sun Belt can't now move plants back overnight.

Strategic Considerations

While we have seen a rather broad range of opinion as to the good news and bad news of just-in-time production scheduling, there is a general view that considerable progress will be made in the next several years. Still, it is equally plain that this is a onerous task that will, at best, happen only gradually, measured on an industry basis. Furthermore, there is considerable subjectivity in a question of this type, in that the definition of true just-in-time is difficult to establish. Does it mean a few minutes of inventory, or would an hour or two hours of inventory be acceptable and still qualify for just-in-time? Furthermore, it has a different meaning when one looks at it with respect to both short and long supply lines. These issues aside, it is clear that just-in-time is apparently a necessary ingredient for the future industry.

TECH-89. What percentage of domestically produced parts and components will be able to meet JIT inventory criteria by 1990 and 1995?

	Median Response		Interquartile Range	
Product Source	1990	1995	1990	1995
OEM Produced	40%	60%	20/50%	40/75%
Outside Supplier	40	60	20/50	50/80

Selected Edited Comments

Depends on schedule stability.

OEMs apply less pressure to internal supply organizations to comply with SPC, JIT, etc., than they do to independents.

The OEM/supplier industries can be expected to mirror each other. If OEMs demand higher percent-compliance internally, suppliers will be driven by same demand. OEMs set the pace.

Theoretically all parts can be put under the JIT criteria, which includes quality, focused factories, group technology, and production leveling, all of which lead to improved productivity.

Discussion

This question is basically a judgment call on the part of the panelists. They believe that by 1990, 40% of both OEM and outside supplier domestically produced parts and components would be able to meet just-in-time inventory criteria. They expect this percentage to rise to 60% for both groups by 1995.

The interquartile range on this question is broad, indicating a wide range of uncertainty or a different applicability of JIT to various parts of the vehicle.

Comparison of Vehicle Manufacturer and Supplier Panelists

For 1990 the vehicle manufacturers forecast a higher percentage for OEM-produced components that will meet JIT inventory requirements (50%) while the suppliers expect a lower percentage (30%) from the OEMs. For 1995 the supplier panelists expect 70% of supplier-produced parts will reach JIT criteria.

Strategic Considerations

Past practices and the rather broad geographic distribution of assembly and component operations in the United States will make the broad application of JIT very difficult. However, it is sincerely believed that JIT is a reasonably fundamental requirement to ensure competitiveness of the domestic industry. Consequently, aggressive moves toward features of the full JIT system or related systems are anticipated.

TECH-90. At the present time what percent of your output is controlled by JIT production scheduling procedures? What will it be by 1990?

	Percent Output Controlled by JIT	
	Median Response	Interquartile Range
Today	10%	5/20%
1990	40	25/60

Selected Edited Comments

We are almost JIT with customers based on the premise that they don't wish to carry as much inventory anymore.

Today's 50% is JIT "delivery," not JIT manufacturing.

Difference dependent on products supplied.

Discussion

The median estimation of all three combined Technology panels is that 10% of the *current output of their company* is controlled by JIT production schedules. These same panelists forecast that by 1990, 40% of their company's output would be controlled by JIT scheduling. The interquartile range does not have meaning for the "Today" response, but represents a spread based on different products, companies, and situations. This holds true to a large extent for the 1990 forecast as well.

Comparison of Vehicle Manufacturer and Supplier Panelists

The percent of output controlled by JIT production scheduling procedures specified by both the vehicle manufacturers and suppliers are identical and in agreement with the combined median responses.

Strategic Considerations

The actual use of JIT is just getting started but, as indicated by the broad interquartile range, the range of output controlled by JIT is great. The expected high rate of growth in JIT may be difficult to attain.

TECH-91. What problems in JIT implementation do you expect will remain unresolved by 1990? Please comment.

The following general response categories have been established to summarize the many thoughtful, yet diverse, responses to this question.

Response Category	Percent of Respondents
1. Supply forecasting and planning will remain difficult to implement	44%
2. Wide distribution of supplier plants and transportation as a continuing problem	24
3. Quality of parts	18
4. Union work rules and work stoppages	9
5. Willingness of suppliers to build satellite plants/ Obsolescence of factory equipment and layout	9
6. Others: Commitment to JIT by all concerned parties; No major problems will exist; Inventory/warehousing; Raw materials supply	

Selected Edited Comments

In the automotive industry, true JIT is impossible for suppliers to achieve given the instability of production schedules of the major automobile manufacturers. Given the competitive situation and the drive for customer satisfaction, the large number of options offered by U.S. vehicle manufacturers and the short delivery time requested by customers ordering cars, variable production schedules are a luxury the automotive industry will continue to pay for several more years.

Our plans typically change so frequently and our supply base too often fails to deliver the requisite quality.

The biggest single problem is that companies are not seriously pursuing JIT. It appears that they are not convinced of all the benefits that can be achieved and are, therefore, not attempting to implement.

Domestic OEMs do not have the discipline of the Japanese. JIT will result in stockouts and shutdowns until OEMs have found the way to cope with JIT—U.S. style. After the shakeout, JIT will cause no major problems. This should be resolved by 1990.

Qualified broadcasts from assembly plants are needed to assure good inventory within a four-hour window. Also, product component compatibility on a day-to-day basis, plus weather will remain as obstacles.

Major problem is that JIT philosophy requires a reorientation of manufacturing capacity, location, etc. Big investments are involved. Much closer supplier/OEM relationships are required before suppliers will make these investments.

Most difficult part of implementation will be to accurately estimate total system cost of alternatives in sourcing and facility decisions.

The testing of material takes up to two weeks; thus JIT is not practical.

Discussion

Eighty-three percent of the respondents within the first two groups were from the supplier sector. Within the third response group, 75% of the panelists expressing this concern for quality were from the OEM sector.

Strategic Considerations

The challenges in bringing full implementation of JIT are obviously substantial. We would anticipate the trend toward regional and local supply locations and full electronic integration of the manufacturers and suppliers will greatly aid the process. The issue of regional and local supply locations is very complex and depends on a number of factors including existing investment, individual organization expertise, and part type. Stamping plants represent an interesting example where the trend is to contiguous stamping but regional facilities may also be used almost indefinitely. In addition, we anticipate that the tremendous pressures on quality will continue to yield a much higher level of component quality. Presently the pressures appear to be absolutely overwhelming in this regard and there is general consensus that a commitment to world-class quality is essential to even be a part of the future industry. Suppliers who cannot match up to the quality requirements are extremely vulnerable, particularly as major new suppliers enter the picture both in terms of transplants and new North American entrants that are beginning to shift levels in the supply structure.

TECH-92. What percentage of engines and transmissions/transaxles installed in U.S.- and Canadian-produced passenger cars by U.S.-based manufacturers will be sourced outside the U.S. in 1990 and 1995? (Include European and Japanese-owned domestic assembly.)

	Median Response		Interquartile Range	
Source of Import	1990	1995	1990	1995
Gasoline Engines				
Japan	15%	15%	6/20%	7/15%
Mexico and South America	10	10	5/10	8/15
Europe	5	5	2/5	2/15
Korea and Other Asia	2	8	0/5	5/10
TOTAL	32%	38%		
Transmissions/Transaxles				
Japan	15	15	4/20	6/22
Europe	5	5	3/10	3/10
Mexico and South America	3	5	0/5	0/10
Korea and Other Asia	2	5	0/5	4/10
TOTAL	25%	30%		

Selected Edited Comments

Expect big jump in off-shore engine (especially Mexico) sourcing between now and 1990. Since high percentage of U.S. transmission/transaxle needs are automatics, only Japanese have domestic capacity/scale to serve U.S. need because Europeans don't make many automatics.

Discussion

The panelists forecast that 25% of the engines installed in U.S. and Canadian-produced passenger cars in 1990 will be sourced from Mexico/South America and Japan. An additional 5% is forecast to be sourced from Europe and 2% from Korea and other Asia. By 1995 the percentage of engines sourced from Mexico/South America, Japan, and Europe is expected to remain at 1990 levels, while the percentage from Korea and other Asia is expected to rise to 8%.

The percentage of transmission/transaxles sourced outside the U.S. in 1990 is forecast to be 15% from Japan, 3% from Mexico/South America, 5% from Europe, and 2% from Korea and other Asia. The percentage from Japan by 1995 is expected to remain at 15% as is Europe at 5%. Mexico and South America are forecast to rise to 5%, as is Korea and other Asia.

Discussion of Panelists' Comments

The single comment reflects the trends indicated by the data and provides a basis for understanding the Japanese share. Ford and GM have large automatic transmission capacity in Europe. In fact, Ford does import automatic transmissions for rear-drive cars.

Strategic Considerations

The complexity of the international scene, with rapid changes in currency valuation and appearance of subtle and not-so-subtle trade barriers, such as local content requirements in many developing countries, suggests that the future is quite unclear with regard to powertrain component sourcing. With continued strengthening of the Japanese yen, one would suspect that Japanese sourcing could diminish. Some suggest that the yen/dollar ratio could approach 90-100 yen per dollar, which would indeed have a profound impact on the fraction sourced in Japan. A key consideration will be the emergence of new North American powertrain components and the availability of capacity in other places in the world. In general, these trends must be watched closely as factors emerge that cause a shift in the expectations of this forecast.

TECH-93. What is your estimate of the percent change (+ or −), in the size of the future U.S. aftermarket for the following parts in the years listed?

Parts	Median Response 1990	Median Response 1995	Interquartile Range 1990	Interquartile Range 1995
	Compared to 1985 Percent Increase/Decrease (if any)			
Electrical/Electronic	10%	20%	5/20%	10/30%
Shock absorbers/Struts	5	4	−3/5	−10/10
Brakes and related	0	0	−5/5	−10/10
Batteries	0	0	−10/5	−10/5
Engine Tune-Up	−3	−6	−10/5	−20/10
Exhaust Systems	−10	−10	−15/0	−25/0
Spark Plugs	−10	−15	−10/0	−25/−4
TOTAL PARTS MARKET*	0%	5%	−8/5%	−10/10%

*Please note that the "Total Parts Market" forecast is a separate estimate. It is a judgment-weighted average of the increases or declines in the total of all individual parts, including those not listed.

MEDIAN FORECASTS FROM THREE DELPHI SURVEYS
SIZE OF FUTURE U.S. AFTERMARKET

Parts	1981 Delphi II	1983 Delphi III	1986 Delphi IV
	Forecast for 1990 at the Time of the Survey		
Electrical/Electronic	N.A.	+5%	+10%
Shock Absorbers/Struts	+4	+1	+5
Brakes and Related	N.A.	+2	0
Batteries	+5	0	0
Engine Tuneup	N.A.	−1	−3
Exhaust System	0	+3	−10
Spark Plugs	−10	−5	−10
TOTAL PARTS MARKET*	N.A.	−3%	0%

Selected Edited Comments

Decline in spark plug market presumes continued decline in number of engine cylinders in vehicle population as downsizing trend continues. Increases in batteries, electric/electronic, recognizes greater electrical power requirements as electric steering and other new electric/electronic systems are introduced. Engine tune-up increase recognizes that vehicles are being kept longer by owner, and higher engine power density trends.

Do not foresee any significant change in aftermarket share through 1995.

Exhaust system increase represents increased replacement of catalytic converter. Brake replacement rate is dramatically up because of (1) FWD weight-load on front primary circuit, (2) pad wear rate set to avoid rotor glaze with non-asbestos, and (3) pad thickness limited to keep caliper small/light.

Higher quality and longer life = lower aftermarket.

Increasing reliability will significantly decrease parts market.

Life of vehicles will continue to increase in age.

Assuming static total fleet size, elimination of leaded gas and spread of emissions inspection requirements beyond metropolitan areas.

Brakes and related parts are currently growing at around 4%.

Included in shock absorbers/struts are electronic suspension system components.

Discussion

Although the electrical and electronic parts aftermarket is expected to expand dramatically and additional growth for shock absorbers and struts is expected, based on panelists' projections, the aftermarket future, as a whole, does not appear to be particularly bright. The most noticeable reductions are expected for exhaust systems, spark plugs, and other engine tuneup parts. These areas are expected to be particularly impacted by forecasted trends in engine downsizing and overall maintenance requirements. Some aftermarket prospects may not appear as gloomy when interquartile ranges are taken into consideration. However, although no firm consensus of opinion appears to be established by the panelists, in general, the high level of uncertainty casts an overall negative expectation for the future of most of the parts surveyed.

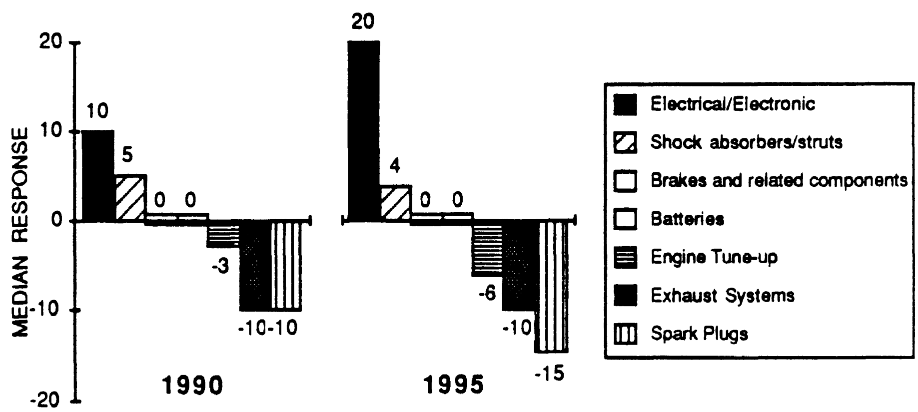

FIGURE T-11(a). Estimate of the Percent Change in the Size of the Future U.S. Aftermarket for Various Parts (Median Responses)

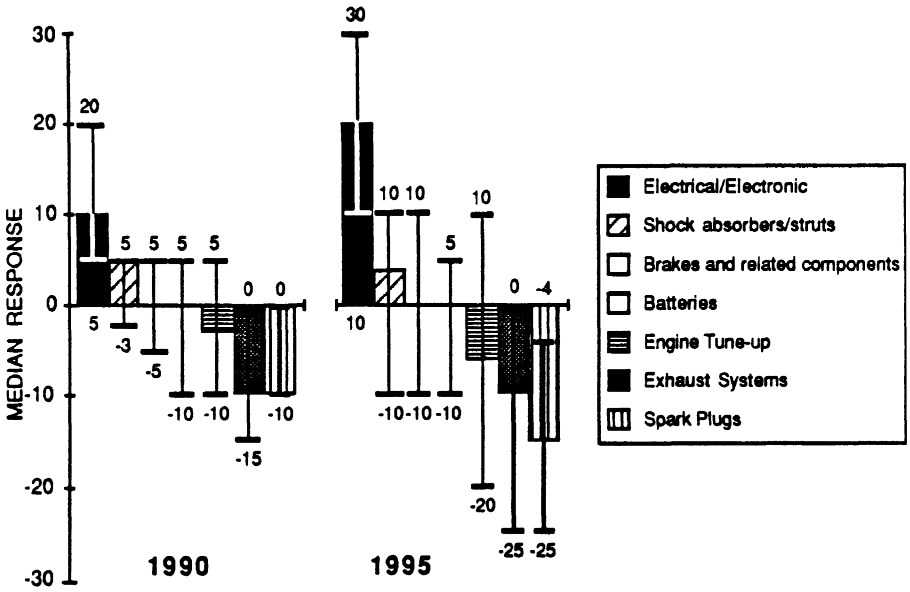

FIGURE T-11(b). Estimate of the Percent Change in the Size of the Future U.S. Aftermarket for Various Parts (Interquartile Ranges)

Discussion of Panelists' Comments

The panelists' comments generally reflect the diversity of opinion apparent from the wide interquartile ranges.

Comparison of Vehicle Manufacturer and Supplier Panelists

For 1990 the vehicle manufacturer panelists forecast a larger negative percent change than did the supplier panelists for exhaust systems, batteries, shocks/struts. This difference accounted for an additional −5% for each part. For 1995 the manufacturers forecast a decrease for batteries, shocks, and electrical/electronic that ranged from 5–10% less than the suppliers. The suppliers forecast a median −10% decrease for engine tuneup, whereas the OEM forecast −5%. It should be noted that the interquartile range for this question is extremely broad (OEM: −50% to +6%; suppliers: −20% to +10%) indicating a very substantial degree of uncertainty as to the direction of the engine tuneup aftermarket, particularly by the OEMs.

Trend from Previous Delphi Surveys

As can be seen in the median table, continued aftermarket growth is forecast for electrical/electronic components and shock absorbers and struts; a continued decline is forecast for spark plugs and engine tuneups. Perhaps as a result of the introduction of new, longer-lasting materials, exhaust systems are forecast by Delphi IV panelists to experience a −10% decline by 1990, whereas Delphi III panelists expected a 3% growth.

Strategic Considerations

The view of the aftermarket is certainly mixed when considering the data in this question. It is evident that quality improvements throughout some areas of the vehicle, particularly in the powertrain, together with reduced number of engine cylinders, will generally reduce the powertrain aftermarket potential. Furthermore, it is increasingly clear that the manufacturers are expected to deliver ever-increasing quality to their customers which, in some respects, might be interpreted as vehicles built with higher quality, lower maintenance requirement components which would infer shrinkage of the aftermarket potential. Also, it was noted that electrical and electronic aftermarket components would be expected to increase. However, with the maturing of this technology, and therefore improved reliability of these components, it is believed that this dimension of the aftermarket must be watched very carefully. While there is no question that the use of electronics will increase, the aftermarket requirements are perhaps more uncertain than are suggested.

Another factor is the role of diagnostics. As diagnostics are improved certain items needing repair are more likely to be replaced. However, at the same time, those not needing repair or replacement are probably not going to be replaced until the need is demonstrated. That is, future replacement may be based on need rather than schedule. The impact on the aftermarket of this strategy at this point is uncertain.

TECH-94. *The following is a two-part question.*

TECH-94A. With the continuing introduction of increasingly complex electronic componentry and subassemblies, vehicles may become more difficult to repair. What impact do you foresee on dealers' service operations? On the "do-it-yourself" market? Please comment.

The following table represents the combined responses of all three Technology panels.

Impact on Dealers' Service Operations	Percent of Respondents
Increased electronic diagnosis and need for specialized equipment	45%
Increased educational needs for mechanics/specialized technicians	35
Increased modular replacement/ increase in unit exchange	19
Increased utilization of dealers's service	15
Increased costs	11
Increase in independent and franchised speciality shops	11

Impact on Do-it-Yourself Market	
Reduced ability for DIY repairs and tune ups	78%
Increased us of "How To" manuals and video cassettes, etc.	14
Increased costs, primarily as a result of the high cost of diagnostic equipment	11
No significant change	7

Additional factors impacting on the "do-it-yourself" market:
- Increased use of modular replacement
- Increased use of on-board diagnostics
- Increased consumer rental/diagnostic service centers
- Use of home computers

Selected Edited Comments

DEALERS' SERVICE OPERATIONS

Service operations will require more discipline to survive. "Shotgunning" will become prohibitively expensive. On-board diagnostics will counter the tendency that vehicles may become more difficult to repair.

Dealerships can expect less outside competition from the "corner garage," increased investment, and increased training needs.

Dealerships will become larger organizations in terms of people and capital equipment requirements. Vehicles will be more expensive to maintain. Customer satisfaction with dealer service will decline.

Manufacturers must train dealers for repair modes for three- to seven-year-old vehicles, not just current year problems.

Electronics diagnostic equipment and training will become critical. Electronic specialists will be used in most dealerships. Diagnostic service will become a "charged" service.

OEMs must do a better job training service operations. Specialty electronic repair shops could develop.

Dealers stand to gain more electronics-related service business, but OEMs must make electronic boxes relatively simple. Expect independent electronics repair specialists to emerge if dealers drop the ball—they may.

There will be increased use of dealers and full-service garages. Increased competition as a market opportunity for garages is perceived.

Vehicles are currently very difficult, if not impossible, for dealers to repair with average mechanics and reasonable levels of time and effort. We must do a better job of simplifying the task and reducing problems.

Increased need for dealer/OEM communication. There will be a shakeout of those dealers that do not "keep up" and therefore provide lower service levels.

If the job is done right, the amount of dealer service will decrease significantly. Self-diagnostics will somewhat limit the amount of dealer-required equipment.

On-board diagnostics will require greater accountability by the dealer, more reliance on "part changes." Customers whose car has told them what is wrong will expect it to be fixed the first time.

Increased "unit exchange" of subassemblies and components with repair/rebuild carried out by manufacturer or specialized repair shop.

Dealers will increasingly become parts exchangers and diagnostics will become increasingly important so that the correct component is changed.

Increased cost of modular replacement (no repairs on this stuff) should be offset by higher reliability and longer durability.

Service, rebuild, and fabrication centers will be needed where dealers will send modules to be repaired.

Dealer service training will be paramount, primarily in terms of electronics and sophisticated diagnostic equipment.

Increased need for "expert system" diagnostic equipment where mechanics are aided in their diagnosis.

Dealer service operations will be on-line to OEM diagnostic and repair computers and will be able to properly service these vehicles.

Foresee shift to TV-repair-type personnel.

Engine, powertrain, and other mechanical repairs will become more costly due to the technical training and understanding required. Initial period will result in more unsatisfied customers due to faulty knowledge and repairs.

Dealer service will continue to be inadequate.

Dealers will have to upgrade service capability significantly or service sector will have dramatic changes and realignment.

Repair facilities will become more sophisticated, more specialized, and more efficient to keep costs down. Greater growth in specialty shops such as Midas, Aamco, etc.

DO-IT-YOURSELF MARKET

Less opportunity for DIY repair due to cost of necessary equipment. Represents a specialty niche for electronic repair business outside of OEM vehicle manufacturers' service operations.

Fewer opportunities for this type of service as both reliability and complexity increase.

Rebuilding or remanufacture of components/subassemblies could increase introducing major modifications in the process.

DIYers will need places to go and rent electronic diagnostic equipment or they will have to stop doing it themselves.

Big market for cheap electronic test equipment and manuals. Fewer casual do-it-yourselfers.

Consumers will become increasingly alienated, "will separate the men from the boys."

Introduction of simple hand-held diagnostic units for less than $400 will allow DIY to continue as present.

Less transmission repair of front-drive vehicles.

Operations will be reduced to mechanical services. Diagnosis of electronic component failures will be symptomatic rather than analytical (measured).

People will become more computer/electronics capable in order to do the repairs.

Pressure will build to introduce do-it-yourself repair modules.

Replacement rather than repair, use of expert system analysis.

Self diagnostics will help, but it is making it more difficult for the DIYer. Some equipment is needed to diagnose problems.

Consumer must invest in more sophisticated and costly tools.

Very limited market. Not only have electronics made "do-it-yourself" difficult, but more crowded engine compartments and less maintainable designs have also made "do-it-yourself" more difficult.

Consumer will find on-board diagnostic systems will lead him to likely area of problem.

Home computers will be some help when we get to network diagnostics.

I would not attempt to work on my own car without the proper equipment. I can't imagine the "do-it-yourself" market remaining significant for service of advanced electronic components.

Limitations to consumer diagnosis will refer even simple repairs to expert DIFM (do-it-for-me) service. Even DIY oil market has peaked, with DIFM increasing.

Present replacement modules will be available to do-it-yourselfer on a partial exchange basis. Rental/loaner diagnostic equipment will become available.

The do-it-yourself market will tend to become restricted to low-technology items, e.g., lubrication, braking lining changes, etc.

Although approximately 30% of the market is made up of "do-it-yourselfers," with the increasing complexity of the automobile, this market will decrease.

Discussion

In a rather straightforward manner, the panelists have basically suggested the "do-it-yourself" market will be reduced considerably with the advent of more sophisticated on-board electronic systems. Of course there appears to be some mitigating factors such as the possible use of new techniques including video cassettes or home computers that could aid the do-it-yourselfer. The possible increase of replacement modules was also noted. Obviously, any new businesses associated with the do-it-yourself market must carefully review their present business strategy in light of these expectations.

Strategic Considerations

From this question and from the preponderance of questions in the entire Delphi forecast, it is clear that the industry is undergoing a very basic transition. This is certainly reflected in the product, which will become more sophisticated, as evidenced by the increased utilization of electronics, and more reliable in the maturing of the technology that is today just in its infancy. Another factor that will have a dramatic impact on the service operation will be the rapid growth in on-board diagnostics that should include forecasting, which would enable replacement or repair of components prior to catastrophic failure, and more sophisticated dealer diagnostic capability. Such systems as a computerized automotive maintenance system (CAMS) and others promise to mature in the next five to ten years, leading to a far more accurate and precise diagnosis. It is felt that the service industry will undergo a very basic transition with the potential reduction of some aftermarket parts, appearance of others, and a much higher level of overall sophistication. This would suggest significant turmoil in the service and parts industry. There appears to be significant opportunities and need for educational mechanisms to improve the skill level of service personnel.

The entire service industry is probably at the beginning of a fundamental revolution. All participants must plan carefully for an uncertain future. Those that attempt to stay the same will probably disappear.

TECH-94B. Which components or subsystems do you expect will become more important for "do-it-yourself" service, and which ones less important by 1990?

MORE IMPORTANT BY 1990
FOR DO-IT-YOURSELF SERVICE

There was consensus among all three Technology panels that routine maintenance factors (to include oil and other fluid checks and changes, filters, spark plugs, belts, hoses, clamps, and diagnostic service) may become more important for do-it-yourself service by 1990.

The forecasts of the Powertrain/Drivetrain Panel and the Body/Chassis Panel each placed emphasis on different systems. They are rank ordered as follows.

Components/Subsystems: Powertrain/Drivetrain Panel	Components/Subsystems: Body/Chassis Panel
Brakes (including linings)	Body panels
Electronic systems (incl. fuses and battery)	Transmission
Fuel system	Lights
Performance and customer appearance items	Brakes
None (9%)	None (14%)

Others (less than 5% of total responses) included: tires; cooling system; audio systems; drive shaft U-joints; steering and suspension parts—struts; engine rebuilds; mechanic systems (Can-Do/Expert Systems).

LESS IMPORTANT BY 1990
FOR DO-IT-YOURSELF SERVICE

Components/Subsystems	Percent of Total Responses
Engine maintenance (incl. ignition system/ spark plugs, fuel system/carburetor, and oil change)	33%
Electrical/electronic systems (incl. fuses and battery)	25%

Other suggestions (5% or less of the total responses) were: suspensions; greasing (due to increased use of sealed-for-life joints and bearings; brakes; tires; AC systems; cooling systems; and corrosion repairs.

Selected Edited Comments

MORE IMPORTANT

These guys are in trouble!

Given that some people devote a constant amount of time to cars, with less time required for maintenance of mechanical items, more will go to appearance items.

Due to the complexity of the engine/drivetrain, there should be more activity in the non–engine/drivetrain areas.

Very few components/subsystems will become more important for DIYs—overall the market will decline. Simple mechanical/electrical components (batteries, some simple mechanical components will remain big DIY items)—DIYs will shift to simple electronics.

LESS IMPORTANT

Ignition systems will not be serviceable; spark plugs may become unserviceable.

With the expansion of fast (10-minute) oil change, people can have this done more conveniently than at home.

By the mid 1990s most of the basic driveline, chassis functions will be too complex for DIY to service. It will be the next century, if ever, when modular black-box design philosophy (like aircraft) would allow DIY to re–enter service of vital systems, with plug–in modules.

Discussion

In general, the panelists are not optimistic about expanded opportunities for do–it–yourself service. However, there was support for routine maintenance items and other parts. Feelings are mixed with regard to the items on the more important list. Areas that are suggested for more do–it–yourself maintenance are generally those that would involve very traditional technology, although there was some suggestion that electronic systems, perhaps by module replacement, could expand. Heading the list of *less* important areas for do–it–yourself maintenance are some of the same factors that were mentioned in the *more* important section. Obviously things related to the powertrain and various electrical and electronic systems generally head the list. Since there is no way to weight the present data, an overall conclusion cannot be drawn on balance. In the prior question it is evident that the less do–it–yourself group is undoubtedly the greatest factor. In this question the intent was to develop the do–it–yourself issue on particular subsystems.

Discussion of Panelists' Comments

The responses to this question closely follow those of the prior question and suggest that the do–it–yourself market is going to be much more tenuous in the years ahead.

Strategic Considerations

See Tech–94A "Strategic Considerations." All evidence suggests that there will be profound changes in the do–it–yourself market with some expanding opportunities but others being reduced significantly. In general, with the combination of greater reliability, reduced maintenance needs, and more complex on–board systems, the do–it–yourself business is likely to experience a fundamental shift.

TECH-95. What is your estimate of the *numerical* percent change (plus or minus) in the size of the future U.S. *aftermarket* for carburetors in the years 1990 and 1995?

	Compared to 1985 Percent Increase/Decrease (if any)			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Carburetors	−10%	−30%	−25/−5%	−60/−15%

Selected Edited Comments

As race sanctioning bodies move to allow fuel injection—carbs will go. Many older vehicles will continue to be serviced.

Our children won't recognize "carburetor" as an English word.

Discussion

It is evident from the median response that a dramatic reduction in aftermarket components for carburetors is envisioned: a 10% reduction by 1990 and a 30% reduction by 1995. The interquartile range is very broad, indicating reasonable uncertainty as to the actual extent of the decrease, but the overall trend is to a decided reduction.

Discussion of Panelists' Comments

Based on other results, it is clear that fuel injection will dominate and will be almost standard. This is reinforced by the comments.

Comparison of Manufacturer and Supplier Panelists

The vehicle manufacturers' estimate of the numerical percent change in the size of the U.S. aftermarket for carburetors in both 1990 and 1995 is double that of the suppliers; −20% and −50% versus −10% and −25%.

Strategic Considerations

Aftermarket opportunities for the carburetor are obviously expected to diminish dramatically. Any supplier of carburetor components would be well advised to rapidly develop alternative business strategies.

INDEX OF QUESTIONS LISTED BY TOPIC

F. Government Regulation

G. Electronic/Electrical Systems Trends

H. Suspension, Brakes, and Tire Trends

I. Powertrain Trends