89-14

THE UNIVERSITY OF MICHIGAN

Automotive Electronics Delphi

AUTOMOTIVE ELECTRONICS DELPHI

August 1989

Published by

Office for the Study of Automotive Transportation
THE UNIVERSITY OF MICHIGAN
Transportation Research Institute
2901 Baxter Road
Ann Arbor, Michigan 48109

This research is self-supporting. Future studies are dependant on revenue from the sale of this publication.

For information, address:

Office for the Study of Automotive Transportation
The University of Michigan
Transportation Research Institute
2901 Baxter Road
Ann Arbor, Michigan 48109-2150
(313) 764-5592

Cover art work by Kathy Crockett Richards,
University of Michigan Transportation Research Institute

Printed in the United States of America

First edition published 1989. UMTRI-89-14

89 10 9 8 7 6 5 4 3 2 1

ACKNOWLEDGEMENTS

We would like to thank our panelists without whose efforts this study could not have been possible, as well as Leonard Groszek of Ford Motor Company who helped launch this study. Additionally, we acknowledge the financial support of our subscribers and sponsors, listed below. Further, we wish to acknowledge the assistance of Lisa Hart, administrative assistant, for coordination efforts; and Richard Doyle, Senior Research Associate, and David Andrea, Senior Research Associate for their advice in preparation of questions, interpretation of results, and in reviewing the final report. We are grateful to Jennifer Jones, Betsy Folks, Tina Jackson, and Marilyn Eller for data entry and word processing efforts. We are also grateful to Andrea Ferrara for editing this manuscript.

William B. Ribbens
Professor of Electrical Engineering
Director of Vehicle Electronics Lab
Guest researcher at OSAT
University of Michigan
and
David E. Cole
Director, Office for the
Study of Automotive Transportation
University of Michigan

Automotive Electronics Delphi Subscribers
Augat-Altair Automotive Group
Borg-Warner Automotive, Inc.
Chrysler Motors Corporation
E.I. duPont de Nemours & Co., Inc.
Fleck Telesis Inc.
General Electric Company
GKN Automotive Components, Inc.
Hitachi America, Ltd.
Intel Corporation
Honeywell Micro Switch Division
Johnson Controls, Inc.
Magnavox Industrial Electronics Division
Nissan Research and Development Inc.
SPX Corporation
Wickes Manufacturing Company

OSAT CORPORATE SPONSORS
Allied Signal Automotive
Donnelly Corporation
Dow Corning, Inc.
Exxon Chemical Americas
Ford Motor Company
General Motors Corporation
ITT Automotive
Mazda Motor Corporation
R. J. Tower Corporation
Textron Inc.
TRW Inc.
Union Carbide Corporation

FOREWORD

INTRODUCTION TO THE STUDY

The Automotive Electronics Delphi (AED) is one volume of a series of studies which attempt to forecast the future of automotive technology. The most recent volume to be published is known as *Delphi V Forecast and Analysis of the U.S. Automotive Industry Through the Year 2000*, as it is the fifth in a series of studies. A relatively small portion of Delphi V is devoted to automotive electronics. The AED, an extension of Delphi V, is devoted solely to the application of electronics to passenger vehicles. The motivation for this study comes, in part, from the phenomenal growth of electronics in passenger vehicles. The Delphi V study, for example, forecast that by the year 2000 roughly 15% of the cost of the vehicles will be devoted to electronics. The AED focuses on the future trends in application of electronics to the automobile as applied to passenger cars and light trucks produced in North America.

THE DELPHI METHOD

General Background

This Automotive Electronics 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 judgement 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 they are moving in a direction that subsequently turns out to be mistaken, the primary concern is to learn what that direction is.

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. In the context of a survey, noise is any phenomenon which interferes with communication including ambient (acoustical) noise as well as psychological factors. (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, the surveyed experts, our 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.

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 key to the success of the Automotive Electronics Delphi survey is the selection of the experts. The Delphi process achieves meaningful forecast only by questioning persons in key engineering/management positions, many of whom can influence the future trends in automotive electronics. For the present study the panelists are about equally divided between automotive manufacturers and the associated supply industry.

USE OF 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 judgement. The Delphi procedures measure the results both of numerical analyses and of judgmental factors being exercised by the experts.

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 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.

PRESENTATION OF STUDY RESULTS

The many forecasts assembled in Automotive Electronics Delphi 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.

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.

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.

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. These sections of the report discuss the relevance of each question to future automotive electronics technology trends.

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.

Strategic Considerations

Based on the replies to the question being discussed, other Delphi V 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.

CONTENTS

EXECUTIVE SUMMARY

The Automotive Electronics Delphi summarizes the results of a study of future automotive electronic technology in the North American marketplace. This study has been conducted using the Delphi method which originated with the Rand Corporation in the 1960's.

The Automotive Electronics Delphi is a part of a series of such studies pertaining to the future of the North American automotive industry. Special emphasis is given to electronic technological forecasts, although market, production, and supplier issues are also explored. The survey conducted during Automotive Electronics Delphi research focuses on the North American-Produced Passenger Vehicle market (NAPPV).

The most recent Delphi study forecasts that electronics will constitute about 15% of the total vehicle cost by the year 2000. The systems having the greatest cost associated with electronics are the entertainment systems; the system with the least electronic cost are transmission/drivetrain and electronic suspension.

The Automotive Electronics Delphi also explores market penetration for new electronic systems. The greatest increases in market penetration will be for anti-lock braking (ABS) and electronically controlled automatic transmissions. Of the many new electronic systems which have been proposed for the North American automotive market, lowest market penetration is forecast for the Head-Up-Display (HUD) and collision avoidance systems.

Slight increases in the percentage of purchased electronics are forecast for General Motors, Ford, and Chrysler. The potential for cost reduction through purchases can improve the competitiveness of the North American manufacturers. The forecasted increase in purchased electronics indicate market opportunities for suppliers of electronic components or systems. The supply industry will play an increasing role in new technology developments although the U.S. manufacturers will retain system responsibility and can be expected to retain the capability to manufacture electronic components in-house. An increase in purchased electronics is also expected by Japanese manufacturers building cars in North America, although the source of purchased electronics was not asked of our panelists.

The Automotive Electronics Delphi panelists see two factors which will significantly influence the commercial introduction of new electronic technology. The first factor is the benefit to the customer in relationship to cost. Panelists see little motivation for introducing new technology simply for the sake of having new gadgets. This viewpoint contrasts with earlier Delphi studies in which new technology was expected to provide a competitive advantage.

The second factor influencing new electronic technology in passenger vehicles is the potential for significant performance benefits such as increased fuel economy or decreased exhaust emissions. Electronic implementation of functions has performance benefits relative to traditional mechanical implementation due to the great flexibility of electronic systems for integration of functions, adaptive control, and rapid system changes via software modifications. Of course this latter factor is related to governmental regulations and is highly susceptible to rapidly changing political issues and environmental concerns.

The primary focus of this Delphi is passenger vehicle electronic technological evolution. This technology involves both system (or subsystems) and electronic components. Among the most important electronic components in any control system are sensors and actuators. Panelists foresee significant new technology required for sensors and actuators for application in engine/drivetrain and electronic suspensions and steering.

It is expected that the automotive suppliers will play an increasing role in developing this new sensor technology. Electronics Delphi panelists foresee needs for new sensors including a cost effective, reliable cylinder pressure sensor for engine control and a torque sensor for electronic transmission control. Improvements in exhaust gas oxygen sensors (in the form of a wide range linear sensor) and a wideband knock sensor are also considered highly desirable.

The very large, traditional suppliers of automotive electronics (e.g., GM Delco Electronics, Ford Electronics Division, Hitachi, and Motorola) seem to be well placed to make required and important new technological contributions. A number of panelists expect these traditional suppliers to increase strength and to put competitive pressure on smaller suppliers (or would be suppliers).

In addition to sensors and actuators, control strategy is a significant factor in implementation of any control system. New control strategy is viewed as being required for integrated engine/drivetrain, electronic steering and electronic suspension controls. These developments will most probably be controlled by the automotive manufacturers. Some of the new electronic technology for engine/drivetrain control which is forecast to have relatively high market penetration (i.e., greater than 80%) includes: distributorless ignition; variable induction system integrated engine/drivetrain control; and multi-point timed sequential fuel injection. In the area of vehicle motion control, anti-lock braking is expected to have very high (greater than 80%) market penetration and in many cases will be combined with total traction control. The consumer will benefit from such developments in the sense of having vehicular improved performance.

Electronically-controlled suspensions are forecast to have a growing but modest market penetration (about 30%) by the year 2000. However, our panelists caution that new technological advances are required in low cost reliable sensors and actuators; control strategy for the nonlinear suspension dynamics as well as generally improved mathematical models for suspension/vehicle dynamics.

In the area of vehicle instrumentation there are interesting trends and developments which have not necessarily been identified in previous forecasts. Whereas prior studies have indicated a relatively high level market penetration for solid state display devices, our panelists are forecasting continued use of analog (including electromechanical devices). Solid state displays are forecast to be used in about 50% of automotive instrument panels. Many panelists suggest that consumer response to digital solid state instrument panels has been somewhat less than expected and that there is still a demand for more traditional instrumentation.

Vacuum Fluorescent (VF) display technology is expected to decrease to only about 30% market penetration by the year 2000. The leading replacement for VF is forecast to be liquid crystal (LQ) with lighting. The LQ technology may be used in about 35% of the solid state display systems.

Some of the new display technologies which are evolving should have relatively high message capability (comparable with cathode ray tube). Reconfigurable flat display panels are forecast to be developed and introduced by the year 2000. Such displays have potential application for advanced driver information systems such as road information or route guidance information.

In addition, multiplexing (MUX) is forecast to play an increasing role during the remainder of the century. This technology will first be used for subsystems, replacing portions of the vehicle wiring harness. For example, MUX should be used in about 40% of the vehicles to link vehicle information systems with various subsystems and in about 30% of the vehicles for door interface controls by about the year 2000. In the related area of communications, our panelists forecast strong resistance to establishing standards for serial data links, although to see increasing use of such digital communications in NAPPV.

Artificial intelligence technology is forecast to have a slowly growing application in NAPPV. For example, approximately 80% of our panelists forecast voice recognition as a driver input for applications such as cellular phone dialing for safety considerations. In addition, expert system technology will find application in service bay diagnostic systems, although this development appears to be more difficult to achieve than was earlier believed.

In the area of electronic technology for NAPPV there will be advances in many areas. "Smart" solid state sensors are forecast to be developed for measurement of displacement and acceleration, pressure and fluid flow or level. Microprocessors will continue to find increased application on vehicles and should number from 10 to 25 per car, depending upon vehicle cost. The 16 bit microprocessor which is already in some use is expected to increase its market penetration particularly for advanced engine/drivetrain control and for electronically-controlled suspensions. Electronic system packaging will use surface mounting technology almost exclusively by the year 2000. Clearly any supplier or would be supplier must have the capability for surface mounting.

The voltage level for NAPPV electrical systems is forecast to increase from the present 12 volts to 48 volts by the year 2000. About 80% of our panelists forecast dual voltage systems of both 48 volt and 12 volt levels. The 12 volt system will be retained to avoid the necessity to redesign all lighting systems and electric motors or solenoids. Electrical current level is forecast to be 100 amp by the year 2000.

Comfort and convenience systems are also forecast by our panelists to see technological improvements. A majority of panelists expect to see zoned climate control and personalized setting of seats and mirrors on increasing numbers of vehicles. These features are expected on hinged vehicles initially with later progression to lower cost cars.

There are many more interesting results of our survey presented in the final Electronics Delphi report than are presented in this summary. In addition to more detailed data, this report also includes comments by the panelists on each question. Furthermore, there is a discussion of panelists responses for each question as well as strategic considerations for each. The strategic considerations provide a brief explanation of the technology for each question and a discussion of the relationship of each technology to the relevant vehicle functions.

I. GENERAL OVERVIEW

1. In NAPPV*, what fraction of the cost of the following major vehicle systems will be represented by electronic components?

	Median Response		Interquartile Range	
Component	1995	2000	1995	2000
Engine	20%	20%	15/20%	20/20%
Transmission/drivetrain	10	15	8/10	10/15
Driver information	30	40	20/40	30/50
Occupant crash protection	20	30	15/20	20/30
Anti-theft systems	50	70	40/60	50/80
Audio and other entertainment systems	80	85	80/85	80/90
Comfort and convenience control	30	40	25/35	30/50
Cruise control	50	50	30/50	30/60
Anti-lock braking (ABS)	30	40	25/40	35/50
Electronically-controlled suspension	20	30	20/30	20/40
Electronically-controlled steering	20	25	10/25	20/35
Traction control	30	40	30/50	30/50

SELECTED EDITED COMMENTS

•(1) The actuators driven by the electronics were also included in percent estimate. (2) The same electronics controller will be used to control the engine, transmission, steering, and cruise; and are lumped together in engine. (3) Many other subsystems will communicate with the engine to share information and have the engine respond as part of their control system.

•Would be helpful to have a definition of electronic component.

•Electronic components mean all forms of semiconductors, resistors, capacitors, and other passive components. I do not include the printed wiring board and assembly components. Semiconductors

*In this report, the abbreviation NAPPV stands for North American-Produced Passenger Vehicles. This includes cars, vans, and light-duty trucks manufactured in the United States and Canada.

and diodes; transistors; SSI, MSI, LSI, and VLSIC; linear, optoelectronic, other discrete components, and hybrids of all above.

•Features--navigation, TV, etc.

•I have included electrically controlled transmission in Transmission/drivetrain category.

•Includes sensors--assumes increasing integration.

•Included electrical as well as electronics (injector, actuators, wiring sensors, etc.). Traction control assumes ABS is present.

•Traction control using brake/throttle combination.

•Concerning occupant crash protection: more airbags and semiconductor accelerometer. Further, the percentages could significantly vary due to different interpretations of electronics content, i.e., is wiring an electronic component, or is an actuator such as a motor considered an electronic component.

•Crime control electronics included in engine anti-theft system will be in part included in engine. ABS will supply signals to engine such as vehicle speed.

•Cruise control as a stand alone system will disappear by 2000. It will integrate into engine/drivetrain control system.

•Incremental electrical/electronic cost of traction control over ABS is 80-95% of total per your definition (includes actuators). I am unaware of proposed traction systems that are not additions to ABS.

•More features will be provided, but cost learning process will be faster for electronic than non-electronic components, so the percentage of cost will not rise as fast as the functionality. Expect multiplexing and integration of the electronics for different systems.

DISCUSSION

The Delphi V Forecast and Analysis of the U.S. Automotive Industry Through the Year 2000 (Technology volume)* presents a number of questions pertaining to automotive electronics. In particular the median forecast for one Delphi V question indicated that the cost of automotive electronics will reach about 15% of the vehicle cost by the year 2000.

The present question expands Delphi V's electronic coverage to include the fractional cost of electronics in individual automotive systems. In this question we are defining electronics to include any active electronic component (e.g., integrated circuits) as well as all related component sensors, actuators, resistors, etc. for the system up to the vehicle wiring harness for the vehicle. Specifically excluded are purely mechanical components (e.g., chassis, mounting structures, etc.).

* See "Introduction to the Study" in the Foreword.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturer and suppliers agree to within 5% for all items except driver information and comfort convenience. In those two cases the manufacturer forecast 10% more and 15% more than the suppliers respectively by the year 2000.

STRATEGIC CONSIDERATION

The spectacular growth of electronics in the automobile has caused automotive electronic systems to constitute a significant portion of passenger vehicle cost. Many modern automotive systems are implemented electronically even if the primary vehicle function is mechanical (e.g., fuel control for engine). In this question we have identified a variety of vehicle systems or functions which have at least a partial electronic implementation and termed these electronic systems.

Electronic systems and subsystems have components which are primarily electronic (e.g., integrated circuits, resistors, capacitors, etc.), but also include non-electronic components (i.e., chassis, control knobs, mounting hardware, wire connectors, etc.). In this question we determine the fraction of system cost which is associated with electronic components. The responses to this question provide a basis for evaluating the details of cost of electronics in automobiles on a system by system basis.

Previous University of Michigan Delphi studies have forecast higher fraction of total vehicle cost represented by electronics than either the most recent Delphi V or the Electronic Delphi study. The reduction in forecast cost comes, in part, because of the reduced time interval from the present to 2000 compared with earlier forecasts and is also due to the reduction in cost/function of electronics. Even though there will be increased numbers of functions implemented in vehicles, the reduction in the cost of implementing these functions at least partially offsets the cost of electronics. In essence the industry is offering the customer more cost effective electronics than in earlier years.

2. What percentage of NAPPV will employ the following electronic/electrical features in the years 1995 and 2000?

	Median Response		Interquartile Range	
Features	1995	2000	1995	2000
Anti-lock braking	40%	75%	35/40%	75/90%
Electronically-controlled suspension	10	30	5/15	15/40
Traction control	10	30	5/10	15/50
Drive-by-wire	5	10	0/5	5/25
Electronic key or keyless entry	15	30	5/20	20/50
Cellular phones	5	20	5/10	10/25
Navigation systems	3	8	1/5	5/15
Information systems	10	20	3/10	15/25
CRT or dot matrix touch screens	3	7	1/5	5/10
Alphanumeric digital IP displays	20	25	10/20	15/35
Solid-state analog IP displays	15	20	10/15	16/30
Electronically-controlled automatic transmission	30	60	20/40	50/70
Continuously Variable Transmission (CVT) (electronic controls)	5	10	1/5	5/10

SELECTED EDITED COMMENTS

•These cellular phone percents are for packaging space consideration in the vehicle. Actual Original Equipment Manufacturer factory installation rates will be low (3% in 1995, 5% in 2000). These information system percents are based on the assumption that "information systems" means external sources such as satellite data/voice links to on-board systems. Self-contained vehicle status information systems (maintenance monitors, diagnostics, and failure warning systems) will be much more prevalent (20% in 1995, 50% in 2000).

•Collision avoidance, 1995=0%, 2000=2%. Liability issues, not technical.

•Near object detection systems, 1995=2%, 2000=5%.

•Truck and van percentages will not be significantly different than cars.

•Drive-by-wire may be needed to handle future emission controls (transients) and will be needed for dilute burn or lean burn control. The control strategy would also be needed for valve train lift and timing control -- a feature which will be seen on many engines run by the engine computer.

•It is envisioned that the federal government will require anti-lock braking as a new model safety feature.

•Electronic key/keyless entry is understated, with cost decreasing, and more features tied to memory functions (HVAC and automatic setting seat position.) Electronic key will dramatically increase in penetration. Solid state analog underrated--strong move that will appear in 1993-1995 drivetrain to cause mechanical analog to decrease substantially and be replaced by electronic analog.

•Most solid state displays are both alphanumerical and analog combinations, and will continue to be so. However, if you include electrical/electronic driven air core type displays, as solid state analog, percentages are and shall remain in the 90's.

•The public hasn't been particularly excited about alphanumeric digital IP displays. Solid-state analog IP displays will depend largely on price.

DISCUSSION

A question similar to the present question was asked as a part of the Delphi V Technology survey. A comparison of the responses for the two studies should therefore be interesting.

Of the electronic subsystems which are duplicated in the Delphi V study the panelists of the Electronic Delphi study generally forecast a higher market penetration than the Delphi V panelists. However, in all cases the median responses for Delphi V were within the interquartile range of the Electronic Delphi responses. This might suggest that the Automotive Electronics Delphi panelists are more optimistic about customer acceptance or the ability to reduce production costs and improve reliability than the wider-based Delphi V Technology experts.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

For 1995 the manufacturers and suppliers agree to within 5% although the manufacturers forecast higher feature usage than suppliers in those cases where there is a difference. For the year 2000 the two panelists groups agree within 5% except for the following categories in which manufacturers forecast higher than the suppliers (the percentage results are manufacturer/supplier) electronically-controlled suspension (30/20), traction control (40/25), drive-by-wire (25/5), electronic key or keyless entry (30/20), cellular phones (25/15).

STRATEGIC CONSIDERATION

All of the functions considered in this question are either in production (or limited production), or will be in production, or have been evaluated in experimental programs. The market penetration for each is influenced by such factors as cost in relation to customer perceived benefit, performance, and reliability.

Although other factors are significant, the market penetration of a given electronic subsystem above is probably influenced most by cost/benefit. Any reduction in cost for components or in the system through improved implementation has the potential to improve market penetration. In the present, highly cost competitive automotive environment such improvements can be routinely expected. In addition, market penetration can be influenced by customer acceptance which tends to grow with time for functions which add convenience to the vehicle and are cost effective.

3. **On a dollar value basis, what is, and what will be the vehicle manufacturers' make/buy ratios for electronic hardware (including sensors and actuators) for the years 1995 and 2000?**

Median Response						
	Current Estimate		1995		2000	
	Make	Buy	Make	Buy	Make	Buy
GM	75%	25%	70%	25%	65%	30%
Ford	50	45	50	45	50	50
Chrysler	40	60	40	60	30	70
Japanese*	15	80	20	80	20	75

Interquartile Range						
	Current Estimate		1995		2000	
	Make	Buy	Make	Buy	Make	Buy
GM	70/80%	20/30%	60/80%	20/40%	55/80%	20/45%
Ford	50/70	30/50	45/70	30/55	40/70	30/60
Chrysler	30/50	50/70	25/50	50/75	20/50	50/80
Japanese*	10/40	60/90	10/40	60/90	12/40	60/88

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

SELECTED EDITED COMMENTS

•GM figures include sub-suppliers through GM component divisions.

•I don't see any of the OEMs staffing with electronic personnel to greatly change the ratios. Buying suppliers is possible for GM and Ford, but not Chrysler.

•Japanese purchases not necessarily from North American suppliers.

•Suppliers affiliated with Japanese OEMs and/or partially owned by them are considered independent suppliers.

•There will be only five big electronic suppliers by 1995: GM Delco, Ford Electronic Division, Siemens, Bosch, and Nippondenso (not in order). Second four: Motorola, Hitachi, Samsung (Korea), Philips.

•These estimates assume only totally in-house make; any subsidiaries, joint ventures, or partial ownership arrangements are assumed to be "bought" hardware.

DISCUSSION

Previous Delphi studies have investigated make/buy ratios for automotive components or subsystems. This particular question surveys electronic hardware make/buy ratios from other automotive components. The median responses indicate a clear trend for North American manufacturers to buy increasing percentages of electronic components rather than make those components themselves. Panelists, as in the past, forecast GM making a larger percentage than it purchases. Ford is moving slowly toward 50/50. Chrysler will buy significantly more electronics than it makes. The Japanese companies in North America will be roughly the same make/buy as Chrysler, which represents about a 5% drop in purchased components from current 1988 estimates. The reader should note the third comment that the Japanese manufacturers outside purchase forecasts are not necessarily North American purchases. For North American suppliers, this is an important consideration and may be substantially different than their traditional domestic customer.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The suppliers forecast consistently about 10% less make than the automobile manufacturers for GM, Ford, and Chrysler, for both 1995 and 2000 and the two groups forecast about the same levels for the Japanese companies in North America.

STRATEGIC CONSIDERATIONS

Although the percentage change in purchased electronics is small, the dollar volumes of purchase are such that the total market opportunity is potentially large. To some extent, the changes seen reflect changes in the overall vertical integration strategy of the North American OEM industry. To have the opportunity to benefit from lower levels of OEM vertical integration, a supplier must be competitive from a technological as well as a cost standpoint. The market opportunities for "electronic" suppliers are substantial.

4. On a dollar-value basis, what will be the percentage of make/buy for NAPPV for the following components by the years indicated?

Median Response				
	1995		2000	
	Make	Buy	Make	Buy
Software	75%	25%	80%	20%
Actuators	20	80	30	70
Sensors	20	80	20	80
Integrated circuits	20	80	20	80
Connectors	20	80	20	80
Switches	10	90	5	90

Interquartile Range				
	1995		2000	
	Make	Buy	Make	Buy
Software	60/90%	10/40%	60/90%	10/40%
Actuators	15/40	60/85	10/35	60/85
Sensors	10/30	70/90	10/30	70/90
Integrated circuits	10/30	70/90	5/30	65/90
Connectors	10/50	50/90	10/50	50/90
Switches	5/20	80/95	0/10	90/100

SELECTED EDITED COMMENTS

•Electronic modules: 1995: make = 80%; buy = 20%. 2000: make = 70%; buy = 30%.

•My response includes control modules, power devices, memories, printed circuit boards, and hybrids.

•Integrated circuits means logic devices, micro-controllers, integrated power devices, memory devices, microprocessors, and analog or linear circuits. I don't include diodes, discrete transistors, and power supplies.

•Software needs to be defined more closely. Firmware might be a better term for the application code used in micro-controller.

•Car companies will form alliances with other companies to increase percent make.

DISCUSSION

This question essentially provides a partial breakdown of components pertaining to question 3. The list of components in this questions is certainly not exhaustive; notably missing from this list are obvious standard circuit components such as resistors, capacitors, and wiring. Typically such components are 100% purchased. The components surveyed here include a majority of the most expensive purchased components. In particular, sensors and actuators tend to be among the most expensive components of any electronic system. Typically actuators are either motors (including stepper motors) or solenoid operated mechanical devices (e.g. fuel injectors, door locks, etc.). We have omitted display type components here because these are covered in later questions in the instrumentation section of this report.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers agree very closely for sensors, switches, and connectors. However, the suppliers forecast about 10% more make than the manufacturers for actuators, software, and integrated circuits for both forecast years.

STRATEGIC CONSIDERATIONS

The revolution in automotive electronics can arguably be said to have begun with electronic fuel control. The motivation for electronics comes in part from environmental and fuel economy regulations. A number of additional electronic functions have, of course, been added to passenger vehicles.

The vast majority of new electronic systems or subsystems (particularly control systems) are realized using the components listed for this question. In fact, these tend to be among the more expensive components.

The results of our survey reveal relatively few new opportunities for the items listed. Standard integrated circuits, for example, which are purchased in large volume, will continue to be purchased by OEMs at about the same average percentage throughout the remainder of this century. In fact, there may be a reduction in purchases by OEMs of actuators and software.

5. What will be the make/buy percentage be for NAPPV for the following electronic subsystems by the years indicated? *NOTE: This question was asked of automotive OEM panelists only.*

	Median Response				Interquartile Range			
	1995		2000		1995		2000	
	Make	Buy	Make	Buy	Make	Buy	Make	Buy
Engine control	80%	20%	80%	20%	75/90%	10/25%	75/95%	5/25%
Cruise control	80	20	80	20	70/80	20/30	70/90	10/30
Instrumentation	75	25	70	30	70/80	20/30	50/75	25/50
Entertainment systems	75	25	65	35	60/90	10/40	40/80	20/60
Comfort systems	70	30	70	30	60/80	20/40	50/80	20/50
Ride control	70	30	70	20	40/80	10/50	50/80	10/50
Steering control	50	40	60	30	35/70	0/60	50/80	15/50
Multiplex systems	80	20	80	20	30/100	0/70	40/100	0/60
Wiring harness (Excluding connectors)	30	70	25	70	20/70	20/80	15/60	30/80
Seat and/or mirror position	20	70	20	75	15/40	40/80	10/50	40/85

SELECTED EDITED COMMENTS

•Multiplex systems will not be a subsystem. Cruise control will be part of engine control.

•GM, Ford, and Chrysler will manufacture most of the electronics of engine control, entertainment systems, and cruise control.

DISCUSSION

This question is related to the subject of question 4, except seen from a system or subsystem viewpoint rather than a component viewpoint, and from the manufacturers perspective. The percent make will remain high for primary systems which have been developed by automotive OEMs (e.g., engine control, cruise control, instrumentation, etc.).

STRATEGIC CONSIDERATION

Although the list of electronic subsystems for this question is not complete, it does represent the significant portions of on-board electronics. As expected, the automotive OEMs will retain control of important electronic systems (e.g., engine control, instrumentation, etc.). The portion of these systems which are purchased are primarily the sensors, actuators, and associated wiring hardware. The actual electronic modules will be built largely by the manufacturers. Purchased components will continue to be standard integrated circuits, circuit elements: e.g., resistors, capacitors, potentiometers, etc.). The percentage buy will continue to be relatively low throughout the remainder of the century. One interesting exception is a slight increase in the buy percentage for entertainment systems. On the other hand, we observe a reduction in purchased steering control systems by the year 2000 compared with 1995. This is interesting, since electronic control is not likely to appear in production in large numbers before 1995. The responses suggest that the automotive OEMs will maintain control of and will construct most of such systems. There seem to be few if any new automotive electronic system opportunities through the end of the century for outside suppliers, with the exception of entertainment and possibly instrumentation. At the first tier level, suppliers need to work with purchasing and engineering groups to obtain sub-system component contacts.

6. Indicate which of the following technical areas, in your opinion, require significant new technology involving major R&D effort by the year 2000 for the specific applications shown.

	Sensors		Actuators or Display		Control Strategy		Signal Processing	
Technical Areas	Yes	No	Yes	No	Yes	No	Yes	No
Engine/drivetrain control	69%	32%	49%	51%	66%	34%	54%	46%
Electronic suspension control	29	71	57	43	6	94	26	74
Electronic steering	60	40	77	23	66	34	46	54
Traction control	40	60	26	74	54	46	20	80
Anti-lock braking system	51	49	60	40	63	37	26	74
Instrumentation	31	69	31	69	23	77	17	83

SELECTED EDITED COMMENTS

•Electronic suspension refers to active suspension.

•Actuation for electronic steering and traction control is expensive, relatively complex and, for traction control, has excessive delay.

•All applications except instrumentation require moving mass quickly and with control.

•Combustion pressure sensors; accurate fuel injectors; higher speed microprocessors; high speed vehicle data link; lean air/fuel control with drive by wire and transmission control; pressure control of transmissions; fail soft control strategy.

•Cost effective/high quality position sensors, significant expert system/AI algorithms for all systems, up-integration architecture.

•Cost effective high pressure fluid sensors, temperature sensors, linear actuators; control system safety, signal process function responsibility.

•Sensors: wheel speed, fuel available, air flow, throttle position. Actuators: injectors, solenoid valves. Low cost displays, system optimization control strategies, memory efficiency--signal processing.

•In general, sensor reliability, accuracy, and cost improvements are needed; actuator reliability, accuracy, and cost improvements are needed. Due to safety implications, control strategy for 4-wheel drive and suspension will be critical to widespread use and acceptance. Emission and fuel economy requirements, coupled with customer expectations of performance, will require engine/drivetrain controls to monitor and act more frequently, yet reliability improvements necessitate less complex input/output. Improved, more efficient signal processing will be critical to accomplishing all of these tasks simultaneously.

•Instrumentation--high contrast, high density, low cost display. Suspension--predictably sense what is coming, then decide what to do.

•Instrumentation--smarter power technology integrated onto a micro-controller; also better forms of display technology. Engine--smart sensors for networking to eliminate part redundancy with other systems. Others need smart power technology for highly integrated actuators (smart actuators). Traction is a function--needs software development. Suspension (fully dynamic) needs fast signal processing.

•Next major task for drivetrain is variable valve timing. This will require major actuator and strategic R&D.

•NOx sensors, high resolution flat displays, and higher speed signal processing.

•Overall integration will be a major task. The various systems must be made to act as a whole.

•Sensors must be developed that are low cost and durable. Color, flat panel displays that are reconfigurable need development. Actuators for active suspension must be developed which are lower cost. Logic to keep electronic steering failure modes safe under all conceivable conditions.

•Smart sensors and actuators for drivetrain control.

•Smart sensors, active suspension.

•Torque sensors, electronic valve actuator, and voice control.

•You need to do a throttle-by-wire system including brake and engine traction control. Need to combine engine and transmission controllers. Need a chassis controller.

•Intra-vehicle data sharing.

•Silicon and/or optical technology must be developed for smart sensor and smart actuators. CASE (Computer Aided Software Engineering) and AI (Artificial Intelligence) technologies will revolutionize software/control strategy. For high-end signal processing, there will be parallel processors and neural networks.

DISCUSSION

The technical areas surveyed in this question are those areas in which clearly defined major research and development efforts are often required for any application. In the recent past there has been considerable expenditure for each area. In this question, we have been interested to see which technical problem areas are generally considered to be "solved" and which continue to need development.

Clearly research and/or development will be needed for sensors, actuators, and control strategy for engine, suspension control, and possibly also for electronic steering. There are potential opportunities for new suppliers areas such as sensor and actuator development.

With respect to instrumentation, only the display is perceived as requiring considerably more research and/or development. The details of the latter R&D are covered more thoroughly in the section of this report devoted to instrumentation.

Signal processing is not seen requiring new development except possibly for engine/drivetrain control diagnostics. This topic is explored in more detail in a later section of this report.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Generally speaking, the manufacturers and suppliers agree to within about 10%, with a few exceptions. In the sensor area, for example, about 20% more manufacturers than suppliers call for more research and development for instrumentation, suspension, traction control and ABS; in the actuator area, about 25 to 35% more manufacturers than suppliers call for new technology; in the signal processing area, about five times as many manufacturers as suppliers call for new technology for ABS. These indicate substantial differences in opinions and offer aggressive suppliers the opportunity to initiate joint R&D efforts with manufacturers to assure common strategic direction.

STRATEGIC CONSIDERATIONS

Sensor and actuators have been, and will continue to be critical components for the success of any electronically implemented function. These two categories probably constitute the major opportunity areas for suppliers, particularly those with specific technology or experience in a related technical field. Signal processing technology is, on the other hand, highly advanced and can be readily adapted to specific automotive applications. Whenever new R&D is required for control strategy, it is typically done by the automotive OEM either alone or in partnership with a specific supplier.

Strategic, technology-based R&D joint-efforts between manufacturers and suppliers may be used by suppliers to develop proprietary systems that, based on superior innovations and cost/benefit factors, will back suppliers into exclusive sourcing arrangements.

7a. What percentage of NAPPV will incorporate Compact Disk (CD) players and/or Digital Audio Tape (DAT) for any application in the following years?

	Median Response		Interquartile Range	
	1995	2000	1995	2000
CD	10%	20%	5/25%	10/40%
DAT	5	20	2/20	10/40

SELECTED EDITED COMMENTS

•Projection based on assumption that CD will have record capability also.

•The above DAT percentages assume that DAT will be successfully introduced in the U.S.

•DAT will put CD business to rest in the next decade.

7b. Please check which of the following functions will use CD players and indicate which years they will become commercially (30,000+ units) available?

	No	Yes	Median Response Year	Interquartile Range Year
Entertainment	3%	97%	1989	1988/1990
Navigation	16	84	1994	1992/1995
Diagnostics	59	41	1994	1990/1995
Data/Message display	59	41	1995	1995/2000

SELECTED EDITED COMMENTS

•Diagnostics, (limited now).

•Beyond the year 2000, solid state memory (EEPROM) could become a cost competitive alternative to the CD.

DISCUSSION

The relatively low market penetration forecast for CD and DAT is an interesting contrast to the relatively high penetration for CD in home entertainment systems. During the past year the CD has out-performed vinyl records and is likely to continue to accelerate. Digital audio tape is just being introduced for home systems but may advance rapidly in home entertainment because of its recording capability.

Clearly the introduction of CD or DAT players in automobiles will be primarily for entertainment and this application has already begun. The so-called CD ROM (read-only memory) has gone beyond the laboratory stage. Furthermore, both of these technologies potentially have record capability and can compete with EEPROM as cost effective data storage. The relatively high level of integration foreseen for vehicular electronics (see question 46.) makes it feasible to use CD or DAT as a localized high density data storage for the applications mentioned in the response to question 7b.

By 1995 the CD is forecast to have navigation applications as well as entertainment. Storage of data for vehicle location and for display maps on two-dimensional display devices (e.g., CRT) is well suited for the CD as a very high density storage medium. The CD also has great potential for storage of data which is useful for diagnostic functions although this function is not foreseen by a majority of panelists.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The supply industry panelists' forecast of half the market penetration for CD and DAT is roughly half of the manufacturers' forecast (CD 15% for 1995; 20% for 2000; and DAT 10% for 1995; 20% for 2000). There is negligible difference in the expected applications although the supply industry expects an average of about one year delay in commercial introduction for each item.

STRATEGIC CONSIDERATION

In the light of the remarkable growth of the CD in home entertainment, it is surprising that the market penetration in NAPPV is forecast to remain relatively low through the year 2000. The digital audio tape (DAT) has a similarly low market penetration for this period. This forecast is less surprising than the CD forecast because DAT has not been established in the mass consumer electronics market.

The motivation for incorporating CD players in passenger vehicles in part comes from the desire to provide the customer with the maximum entertainment flexibility. The shift from vinyl disks and to some extent from analog tape to CD in the recording industry suggests that automotive manufacturers might want to give customers the chance to use expanded CD repertoire of music or lectures/stories which are becoming available.

In addition the capability of storing large amounts of data which can be rapidly and conveniently retrieved for such applications as navigation is further motivation for including CD players in cars. The capability to record on CDs which will probably soon be available will be an additional motivation which will spur the use of CDs.

8a. Do you expect to see the introduction of radar on production (30,000+ units) passenger vehicles? If yes, please indicate year.

		Median Response Year	Interquartile Range Year
Yes:	80%	1996	1995/2000
No:	20%		

SELECTED EDITED COMMENTS

•Cost/reliability issues to be resolved.

•I expect a method with less chance for cross talk, but require more standby processing to be adopted for collision avoidance.

•It will require this long to make a system with sufficiently low rate of errors (omission or commission).

8b. List the applications you foresee for automobile radar.

Application	Percent of respondents who listed each application
Collision avoidance	62%
Obstacle detection	32
Automatic highway applications	30
Station keeping	20
Backup warning	20
Speed sensing	17
Navigation	3

SELECTED ADDITIONAL APPLICATIONS

•Blind spot indicators. Vehicle to vehicle warning.

•Proximity sensing for lane change. Some of these applications could be achieved with sonar.

•Drive-by-wire, ABS, and suspension control.

•Crash avoidance. Inflatable restraint triggering.

•First applications will be passive or warning, not active avoidance.

•Near obstacle detection and adaptive cruise control.

•Speed vs. proximity to obstruction warning. Rear view proximity warning and drive-by-wire or active suspension input sensor.

•Warning of approaching too close/too fast to forward traffic. Warning that following traffic is approaching too close/too fast. Warning that it is not safe for lane change.

•Ride control.

DISCUSSION

The future for automotive radar is difficult to predict because of the various technical problems. A relatively large percentage of panelists expect to see introduction of automotive radar with 30000+ units. The forecast time interval 1995-2000 is indicative that the panelists see progress being made in solving some of the technical problems.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Roughly 10% more automobile manufacturers (i.e., 85%) expect widespread commercial introduction of radar than the supply industry. Both groups forecast the same applications.

STRATEGIC CONSIDERATION

Experiments with automotive radar have been conducted at various levels over the past 15-20 years. Radar has several obvious potential applications for collision avoidance and threat warning. However, at the present time the problems of discriminating against fixed (e.g., trees near roadside), or moving non-threat targets has not been fully solved for all possible circumstances. Research is on-going and the possibility exists of the development of a commercially feasible system.

There is an additional practical problem of the cost of an on-board automotive radar system. However, as in the case of consumer electronics, in general, the cost/function for successful electronic systems decrease with time and with market penetration. Thus, it is conceivable that the cost of automotive radar systems will decrease substantially with increased production volume.

Additional automotive applications include true vehicle speed sensing (via Doppler radar), station keeping, and backup warning. Each of these applications involves technical problems which have precluded commercial introduction. For example, Doppler radar speed measurements would have great potential for anti-lock brake systems. However, the conditions under which the speed measurement is most needed correspond to the conditions in which the reflected radar signal is at a minimum (i.e., wet or icy road surface).

9. Assuming all cars will be equipped with seat belts, what percentage of NAPPV will utilize the following additional safety features for front seat occupants in the years 1995 and 2000?

	Median Response		Interquartile Range	
	1995	2000	1995	2000
Passive belt restraint systems	30%	30%	30/35%	25/35%
Air bags:				
Driver only	20	20	10/35	10/50
Driver and passenger, front	15	50	10/40	30/70
Rear seat occupants	0	5	0/1	0/10
Air bags - plus passive restraint	10	15	0/30	5/40

SELECTED EDITED COMMENTS

•I strongly object to any mandated shift to passive systems which do not offer the option of utilizing a three-point harness or equivalent as part of, or supplement to, the mandated system, i.e., no airbag only systems.

•The cost/benefit ratio for airbags will restrict public demand--but Washington could affect the evolution.

•Total friendly interior is a possibility.

•"Smart" active belt systems. Although seat and belt sensor systems to disable vehicle starting could be easily defeated in the past, new systems can be developed using one of the on-board computer systems or a smart sensor to insure passenger belts are always fastened before car will start and must remain fastened to keep vehicle running or light a beacon if they are disconnected.

•Passenger side restraint system offering will be driven by customer voice (i.e., 50% of vehicles will have passenger air bags).

DISCUSSION

There are many factors involved in the choice of occupant protection systems. This question does not attempt to address these issues. Rather, this question examines only the relative use of the two major electronically implemented protection systems. Panelists have quite strong opinions on mandated occupant protection systems. The airbag does become the system of choice for our panelists by the end of the century.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and supplier agree within 5%.

STRATEGIC CONSIDERATION

Predictions on this topic are relatively difficult to make because of the overwhelming influence of the federal government. Washington could react rather suddenly to political pressure to affect the final configuration for occupant protection. However, no matter what occupant protection technology is used the trend is toward protection of all occupants and gives significant opportunities to electronic/electrical suppliers for components and subsystems.

II. ENGINE AND DRIVETRAIN

10. **This question pertains to vehicles equipped with gasoline-fueled engines and automatic transmissions. Assume that a cost-effective sensor was available for each of the following combustion feedback variables. Please rank in order the preferred feedback variables (1 = most preferred, 7 = least preferred) for control of the indicated variable.** *NOTE: Entries in table represent percent of respondents who selected each category.*

Mixture							
Feedback Variable	Preference						
	1	2	3	4	5	6	7
Cylinder pressure	31.3%	31.3%	25.0%	12.5%	0.0%	0.0%	0.0%
Knock acoustic signal	0.0	50.0	20.0	0.0	20.0	0.0	10.0
Exhaust gas chemistry (including EGO sensor)	85.0	15.0	0.0	0.0	0.0	0.0	0.0
Ionization probe	40.0	26.7	13.3	13.3	6.7	0.0	0.0
Crankshaft angular speed	16.7	16.7	33.3	8.3	8.3	8.3	8.3
Crankshaft angular position	0.0	58.3	8.3	8.3	8.3	8.3	8.3
Torque	0.0	45.5	36.4	9.1	0.0	9.1	0.0

Ignition Timing							
Feedback Variable	Preference						
	1	2	3	4	5	6	7
Cylinder pressure	52.6%	26.3%	5.3%	5.3%	10.5%	0.0%	0.0%
Knock acoustic signal	35.3	17.6	23.5	17.6	5.9	0.0	0.0
Exhaust gas chemistry (including EGO sensor)	0.0	63.6	9.1	0.0	0.0	18.2	9.1
Ionization probe	0.0	53.8	23.1	0.0	7.7	0.0	15.4
Crankshaft angular speed	35.7	35.7	14.3	7.1	0.0	7.1	0.0
Crankshaft angular position	56.3	18.8	6.3	18.8	0.0	0.0	0.0
Torque	7.7	30.8	23.1	23.1	15.4	0.0	0.0

Feedback Variable	Transmission Shifting Preference						
	1	2	3	4	5	6	7
Cylinder pressure	7.7%	23.1%	61.5%	0.0%	7.7%	0.0%	0.0%
Knock acoustic signal	0.0	11.1	44.4	11.1	22.2	11.1	0.0
Exhaust gas chemistry (including EGO sensor)	0.0	11.1	55.6	11.1	0.0	22.2	0.0
Ionization probe	0.0	0.0	55.6	22.2	0.0	0.0	22.2
Crankshaft angular speed	18.8	56.3	18.8	6.3	0.0	0.0	0.0
Crankshaft angular position	0.0	10.0	60.0	20.0	0.0	0.0	10.0
Torque	84.2	10.5	5.3	0.0	0.0	0.0	0.0

SELECTED EDITED COMMENTS

•Mass airflow sensor: mixture=2, ignition timing=2, transmission shifting=2 (2=important).

•No major shifts from existing technology before 1996/1997. Linear exhaust gas oxygen sensor is highly probable. Torque for transmission control is favorable. Direct combustion sensing (ion or pressure) will be cost driven.

DISCUSSION

The vast majority of panelists (i.e., 85%) expect exhaust gas oxygen (EGO) to continue to be the preferred feedback variable for mixture control, even if measurements of other variables were cost effective. For the second choice variable the ranking is: crankshaft angular position, knock acoustic signal, and torque. It is curious that a cylinder pressure ranks relatively low for mixture control as this variable has the potential to provide the most information possible concerning engine performance.

For ignition timing, the cylinder pressure measurements and crankshaft angular position rank first. At the present time the knock acoustic signal is the only feedback variable for ignition timing. It is still the first preference by the panelist although by a relatively low percentage.

For transmission shifting, torque is clearly the preferred choice among panelists, with RPM (camshaft angular speed) as a second choice.

Although the preferred mixture control feedback variable is EGO, there are potential opportunities for cost effective cylinder pressure or ionization probe sensors. These same variables afford opportunities for ignition control. A clear and unmistakable opportunity exists for a driveline torque sensor for transmission control. To be most useful, this sensor should probably also be non-contacting. However, in spite of considerable R&D expenditure, there is still no cost effective torque sensor.

STRATEGIC CONSIDERATIONS

Since the inception of electronic air/fuel mixture control for engines, measurements of EGO level have provided the only feedback variable. Other measurements (including mass air flow, manifold pressure, RPM, coolant temperature, etc.) have been used in a feed-forward, open loop mode of operation. This question has attempted to ascertain opportunities for sensor research and development in the area of electronic engine/drivetrain control. The panelists have been asked, in effect, to assume that no limitations are imposed upon engine/drivetrain control and to express preferences for feedback variables. Any preferred variable for which a sensor is not commercially available represents a potential opportunity. In interpreting the results of this question, please note that each row sums to 100% (approximately, within round-off error) for each variable. Thus, the percentages given indicate the preferred ranking for each variable.

11. For this two-part question, presume that exhaust gas emission constraints will either remain the same or become more severe.

11a. Do you foresee a change in air/fuel from the present stoichiometric mixture ratio? If so, please indicate the year in which there will be commercial (30,000+ units) introduction of a non-stoichiometric mixture.

			Median Response	Interquartile Range
Yes:	59%	Year Introduced:	1995	1995/1995
No foreseeable change:		41%		

SELECTED EDITED COMMENTS

•Depends on government CAFE requirements.

•Increased pressure to lower emissions including currently unregulated gases.

•Lean burn strategy.

•Lean burn mixture fraction invariably causes driver complaints. Stoichiometric mixture will be around for a long time.

•Rhodium shortage will force move to lean mixture control.

•Will be in the interval 1993-1995.

11b. If yes, what electronic control system technological developments will be required for operation at mixture ratios other than stoichiometric (e.g., low cost, wide range exhaust gas oxygen sensor)?

Potential Electronic Control Systems	
Technological Development	Percent of respondents who listed this development
Linear exhaust gas oxygen sensor	80%
Torque sensor	40
Cylinder pressure sensor	13
Wideband knock sensor	13

SELECTED ADDITIONAL DEVELOPMENTS

Event driven software.

High resolution crank sensor, accurate mass airflow sensor, accurate fuel injectors, and fuel pump pressure control system.

Improved spark plugs.

Flame emission sensor, and fine atomization injector.

Ignition systems for lean burn--multi-strike or continuous.

DISCUSSION

The very strong consensus of those who expect a change to occur in 1995 is very interesting. The majority of panelists who expect a change in fuel control strategy believe that some form of lean burn strategy will evolve (i.e., 59% of the panelists). The second part of the question deals with forecasting the technical changes which must occur. For example, the currently used exhaust gas oxygen sensor, which is used during closed loop operation, functions usefully only for stoichiometric mixture.

The linear exhaust gas oxygen sensor is projected by the majority of panelists as the technical development required for non-stoichiometric mixture. This sensor must have reliable performance with stable calibration for mixture ratios from about 12 up to about 21 or 22 air:fuel. However, this sensor will only be involved in active control for closed loop mode of operation. There are other technical developments which are required for lean mixture control for open loop operating mode such as an accurate mass airflow sensor, accurate fuel metering, and improved ignition of lean mixtures. Opportunities appear to exist for developments in these areas.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

There was a significant difference between the percentage of manufacturer panelists who expect a change from stoichiometric mixture (67%) relative to the suppliers (50%). The change is expected by both manufacturers and suppliers to occur around 1995. Both groups suggested that a linear wide range exhaust gas sensor will be required for the change.

STRATEGIC CONSIDERATIONS

Stoichiometric mixture is required in order to meet EPA emission requirements for any vehicle equipped with a 3-way catalytic converter. The only suitable mixture ratio for which acceptable conversion efficiency is achieved for hydrocarbons, CO, and NOx is stoichiometry. The responses of the panelists indicate a trend away from of stoichiometric control strategy. Some of the motivation for change includes potential regulation pressure to improve fuel economy (CAFE) and a possible move for tighter exhaust emission constraints including regulations on presently unregulated gases.

The shift from stoichiometry to a lean burn strategy has the potential for improved fleet fuel economy (CAFE), and for achieving NOx emission levels without requiring a reducing catalyst. Control strategies for lean burn mixture control have been evaluated experimentally with small but measurable performance improvement. However, at the present time there is some debate about whether lean burn is a viable control strategy. The wide range (piece wise linear) EGO sensor is probably the only feasible sensor for feedback control. To some extent, the availability of a cost effective linear EGO could influence the implementation of an alternate control strategy.

12a. What percentage of engines in NAPPV will utilize variable induction systems (e.g., variable valve timing, intake manifold geometry, etc.) by the years indicated?

Median Response		Interquartile Range	
1995	2000	1995	2000
10%	20%	5/10%	10/35%

SELECTED EDITED COMMENTS

•Future standards for emissions and fuel economy, alternative fuels will drive the development of valve train control.

•This feature would be accelerated by a sharp increase in fuel prices.

•Benefits now being obtained and understood.

•Manifold throttling (trombone/trumpet) will occur before valve timing control. Valve timing is the ultimate answer. Both will be cost driven.

•Only crude electronic versions; not fully integrated per cylinder until past the year 2000.

•The limiting factor will be actuator size and cost. Cam driven 4-valve/cylinder is potential competitor.

12b. Which of the following methods will be utilized for accomplishing variable induction by the years indicated? Please estimate fraction of vehicle which will incorporate these methods by the years indicated.

	Median Response		Interquartile Range	
Variable Induction Methods	1995	2000	1995	2000
Variable valve timing	10%	35%	2/20%	10/50%
Variable intake manifold geometry	5	20	2/50	8/50

SELECTED EDITED COMMENTS

•We hope that variable valve timing will come about 2000.

DISCUSSION

Although the market penetration forecast through 2000 is modest for variable induction systems (i.e., 20%) the trend appears to be increasing. The panelists expect variable valve timing to dominate ultimately. However, the variable intake geometry may be the earliest method in widespread production because of its relative simplicity and potentially lower cost.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and supplies agree within 5%.

STRATEGIC CONSIDERATIONS

The induction system for an engine consists of the intake manifold, the valves, and the camshaft. The volumetric efficiency, which is a measure of the performance of the engine as an airpump, is influenced by the induction system configuration and characteristics. Typically for an engine, the design of the induction system involves a series of compromises to achieve a generally balanced performance over the full operating range of the engine.

A variable induction system has the potential to improve the pumping performance of an engine by eliminating some of the constraints in the compromised system design for different air flows. Some of the methods which have been proposed to achieve variable induction system include varying intake geometry and variable valve timing.

The majority of the panelists prefer to achieve variable induction through variable valve timing. However, the technology to achieve this is yet too costly relative to variable intake manifold geometry. Once the technological problems have been overcome, variable valve timing is expected to replace variable intake geometry and achieve moderate market penetration.

Both variable geometry and variable valve timing methods involve somewhat complex mechanisms and control systems. Consequently the benefits derived must be non-trivial in order to justify the cost. A number of experimental systems have been developed and tested but widespread commercial introduction appears to be in the future for North American manufacturers. It is likely that variable induction systems will be applied first to relatively high performance vehicles.

13a. What are the major factors limiting widespread use of interactive electronic engine/transmission controls? (e.g., sensor availability, cost, etc.) Please rank in order (1 = most limiting, 6 = least limiting) the following factors.

Powertrain Controls						
Limiting Factors	Ranking					
	1	2	3	4	5	6
Customer perceived value	35%	0%	35%	20%	5%	5%
Lack of suitable sensors	16	21	37	21	5	0
Lack of suitable actuators	21	32	21	21	5	0
Lack of adequate data link	0	20	5	15	60	0
Incomplete development of fully electronically controlled transmission	25	25	5	20	20	5

SELECTED OTHER REPRESENTATIVE FACTORS

- There is not a transmission that would justify the cost of going interactive.

- Control system strategy with acceptable fail soft modes; electronic transmission availability; faster microprocessing, drive-by-wire actuator, high resolution, low cost crank sensor.

- Data link--reliability and speed.

- Design verification for system reliability (failure modes).

- Development of fully electronic transmission controls is not yet adequate to realize the benefit; by 1995 this will not be the case.

- Effective processing power. Can not (do not) have enough power to do everything interactively. Must use independent systems.

- Lack of effective techniques to model, implement in software, and measure the benefits of complex systems.

- Lack of systems engineering.

- OEM inertia.

- Reliable actuators and back-up systems are not available now.

- Sensor and actuator availability at low cost.

- Sensors and actuators to interface with electronics effectively (cost and performance).

- The lack of cost effective multiplexing. Today and over the next 5-7 years, transmission control will either be its own system (simple and cheap) or integrated into the engine control module (processor and pin connector limited). Smart sensors equal distributed control.

•Torque sensor availability and control strategies developed software.

•The auto companies are not aggressively attacking at this time as they should. Sensors are also a major factor, lack of development of electronic controlled transmissions is also a factor, much too late.

SELECTED EDITED COMMENTS

•I believe many of the Japanese companies and European companies are working very strongly in this activity and their vehicles will introduce interactive control before the American companies even begin serious development.

•Control system strategy and high level language which works well with a more powerful microprocessor [required].

•Cost on low end vehicles = 1.

•Biggest issue is still customer-perceived value. Drive a new Pontiac 6000 with 4-wheel drive on a dry day; the driver cannot feel or see the benefits, but is still paying for them.

•Fully integrated systems are a reality today.

•You've now assumed there will be interactive electronic control of the engine and the transmission.

13b. By what year will there be widespread commercial use of electronic interactive engine/transmission control?

	Median Response	Interquartile Range
Year:	1995	1995/1998

SELECTED EDITED COMMENTS

•The transition is coming, but slowly.

DISCUSSION

There seems to be little doubt that the panelists believe that customer perceived value is the most important inhibiting factor in integrated interactive engine/transmission control. Lack of suitable, cost effective sensors and/or actuators rank second and third, with about equal voting.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The rankings for the two groups are as follows:

	Manufacturers	Suppliers
Customer perceived value	1	1
Lack of suitable sensors	3	2
Lack of suitable actuators	2	4
Lack of adequate data link	5	5
Incomplete development of electronically controlled transmission	4	3

STRATEGIC CONSIDERATIONS

Interactive control of the engine and drivetrain has several potential performance advantages over individual control of the engine or drivetrain. Of course, electronic transmission control must be fully realized before interactive engine transmission control can be achieved. By controlling both engine and transmission, optimization of performance factors such as fuel economy or torque can be achieved.

The panelists' concerns show that customer perceived value may be a very serious limitation to the introduction of interactive engine/transmission control. Probably the vast majority of car owners have no concept of electronic controls and as such might find little perceived value for the system. If significant performance (e.g., torque or horse power, fuel economy) benefits were achieved then it would be necessary to explain to the owner that the benefits come from advanced engine/transmission control.

However, new tighter emission constraints and higher CAFE standards can replace customer issues as motivation for interactive engine/transmission control. In this case, the motivation for interactive engine transmission control will be provided by the government.

14. What percentage of NAPPV will use distributorless ignition systems (DIS) in the following engine configurations by the year indicated?

Distributorless Applications				
Engine Configuration	Median Response 1995	Median Response 2000	Interquartile Range 1995	Interquartile Range 2000
4-cylinder	50%	80%	40/60%	70/100%
6-cylinder	50	75	30/60	50/100
8-cylinder	20	60	10/40	25/100

SELECTED EDITED COMMENTS

•May happen faster than 1995-2000 interval if aerodynamics is emphasized or RFI regulations are tightened.

DISCUSSION

The panelists clearly favor DIS for 4- and 6-cylinder engines. To a lesser extent this is true for V-8 engines although even in this later case more than half the panelist expect DIS in the majority of vehicles. Roughly the same fraction of 4-cylinder and V-6 engine configurations will incorporate DIS. The fact that 25% of the panelists expect DIS to be in 100% of the NAPPV is significant.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The supplier panelists forecast generally 20 to 30% less market penetration for DIS than manufacturers for both years across all configurations.

STRATEGIC CONSIDERATIONS

In distributorless ignition systems (DIS) the distributor is replaced with multiple coils. In one such DIS configuration there is a single coil for each pair of cylinders (assuming even number of cylinders). A pair of cylinders is ignited simultaneously, one during compression, the other during exhaust. Of course, there are other configurations and combinations of coils/cylinders.

A DIS configuration has the advantage of eliminating the rotating parts which are associated with a normal distributor and which can wear. Another potential benefit of a DIS configuration is the possibility to individually control ignition for each cylinder which can improve fuel economy and torque uniformity. However, except in the case of a 2 cylinder engine, a DIS may require more coils than a conventional system.

15a. For NAPPV equipped with distributorless ignition systems (DIS), what percentage will sense crankshaft angular position at the following location by the year indicated?

	Median Response		Interquartile Range	
Crankshaft Angular Position Locator	1995	2000	1995	2000
Crankshaft	80%	95%	80/90%	90/100%
Camshaft	20	5	10/20	0/5

SELECTED EDITED COMMENTS

•This may be influenced by camshafts going with electrical or hydraulic valve movers.

•Internal engine sensing will increase.

•Piston position, peak pressure; 1995=0%, 2000=5%.

•Even with a camshaft sensor for valve train control, spark position an engine RPM will be based on crankshaft sensing.

•Camshaft sense is required for sequential fuel.

•I don't appreciate why this is particularly important, unless camshaft "phasing" is employed; in that case crankshaft position sensing is far better. What is the driving force for cam sensing?

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and supplier agree to within 5%.

15b. In measuring crankshaft angular position for ignition timing purposes, what sampling interval (resolution) in crankshaft degrees will be required for the years indicated?

	Median Response		Interquartile Range	
	1995	2000	1995	2000
Sampling interval (in degrees)	3	1	1/5	0.5/1

SELECTED EDITED COMMENTS

•At low peaks, + or - 0.5 degrees, at high speeds + or - 3 degrees, regardless of time.

•Depends on system design. You will need 1/2 to 1 degree spark placement accuracy. Crankshaft sampling depends on how you design.

•Other engine electronic systems may require this resolution sooner, i.e., valve timer.

•Software techniques can obtain 1% accuracy with pulse/cycle hardware.

•Three to four degree of spark firing accuracy is probably sufficient. This could be achieved with a 20 degree resolution sensor with a prediction on engines of typical moment of inertia and with automatic transmission.

•Probably need high resolution for valve timing control.

•Depends on system design.

•Little reason to go below 5-10 degrees because nonlinear interpolation is accurate except for very low inertia engines.

DISCUSSION

The clear benefits of sensing engine angular position at the crankshaft as opposed to the camshaft are reflected in the survey results. By the year 2000, a majority of NAPPV will incorporate DIS ignition (see question 14). Nearly all of these systems will sense engine position at the crankshaft.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Both manufacturers and suppliers agree to within 2 degrees of crankshaft angle.

STRATEGIC CONSIDERATIONS

With respect to suppliers of engine position sensors (the majority will be Hall effect devices), the difference between camshaft and crankshaft position sensing is probably more a question of sensor configuration than overall cost. However, the suppliers of such sensors should be well aware of the trend toward crankshaft position sensing and the trend toward relatively high sampling rates (from 15b).

16. Please rank order the preferred method (1 = most preferred, 5=least preferred) crankshaft angular position in the years indicated. *NOTE: Value in table is percent of respondents who chose that ranking for the corresponding method.*

Crank Angle Sensor	1995					2000				
	1	2	3	4	5	1	2	3	4	5
Hall effect	83%	6%	6%	5%	0%	63%	18%	13%	6%	0%
Magnetic induction	14	43	29	0	14	46	27	9	18	0
Optical	9	37	18	36	0	0	31	31	23	15
Magnetoresistance	8	31	15	46	0	0	25	25	50	0
Capacitance	0	0	20	10	70	0	0	22	0	78

SELECTED EDITED COMMENTS

•Best cost/quality. All seem effective. The most durable and cost effective for 1995 primary worldwide will be variable resistance, or Hall.

•Optical and capacitive are too susceptible to contamination, magnetic induction is usually speed sensitive. Eddy current may be needed for non-magnetic conducting crankshafts. Eddy current will be third preferred method by 1995.

DISCUSSION

The interpretation of the results of this question require a bit of explanation. The leading choice for crankshaft angular position measurement through 2000 is the Hall effect. However a smaller percentage (63%) of respondents believe that Hall effect will be the first choice in 2000 than in 1995. Furthermore it is relatively clear that capacitive sensors are a fifth choice and that magneto-resistance is a 4th level choice through the year 2000. Although the voting is somewhat less clear for the second and third choices than for other choices it would appear that the ranking indicates magnetic induction as a second or third choice through 2000.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The ranking for 1995 was nearly identical for both manufacturers and suppliers. By the year 2000, however, the suppliers expect Hall effect sensing to continue to dominate by a higher percentage than manufacturers. The second choice for both groups for 2000 is optical.

STRATEGIC CONSIDERATIONS

The Hall effect sensor has one primary advantage over magnetic induction or capacitive sensor methodologies. The calibration of this sensor type is virtually independent of speed and is capable of even zero speed crankshaft position sensing. This is advantageous for end of line testing as well as for diagnosis and maintenance purposes. Furthermore, the optical sensor, although capable of zero speed position sensing, is susceptible to dirt contamination. A capacitive sensor is susceptible to calibration drift due to oil coating, etc. It is probably due to these potential problems with other technologies that the Hall effect sensor is the preferred choice of the panelists.

The message to suppliers of crankshaft position sensors appears to be that any potential replacement for the Hall effect sensor should be capable of static position sensing and should have stable calibration throughout the engine lifetime. The Hall effect sensor will continue to dominate crankshaft position sensing through the year 2000. However, alternate choices (e.g., optical position sensing) is a potential replacement.

17. What percentage of NAPPV will utilize ultrasonic atomization for better performance in single point or throttle-body fuel injection (TBFI) systems performance by the following years?

Median Response		Interquartile Range	
1995	2000	1995	2000
0%	2%	0/5%	0/10%

SELECTED EDITED COMMENTS

•Single point systems will be phased out in favor of multi-point or air applications.

•TBFI will not be predominant.

DISCUSSION

The panelists are not enthusiastic about this technical development, which involves obsolescent single point fuel metering systems. The responses, however, might be quite different for ultrasonic atomization applied to multi-point fuel injection which is currently under experimental development. For multi-point fuel metering, it is necessary to incorporate an ultrasonic transducer for each injector. The relative cost/benefits are not favorable for multi-cylinder fuel injection.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The responses of both groups to this question were nearly identical.

STRATEGIC CONSIDERATIONS

There does not seem to be a market to justify a large R&D effort toward ultrasonic atomization for single point fuel injection systems. There may be a market for vehicles incorporating multi-point ultrasonic atomization fuel injection. This latter point will likely be surveyed in future Electronic Delphi studies after performance benefits for this injector have been evaluated.

18. What percentage of NAPPV with V-6 or V-8 engines that utilize multi-point fuel injection will also use timed sequential or bank switched methods by the years indicated?

	Median Response		Interquartile Range	
Firing Methods Used	1995	2000	1995	2000
Timed sequential	50%	80%	50/70%	70/90%
Bank switched	50	20	30/50	5/20
Programmed*	0	0	0/1	0/10

**Single response*

SELECTED EDITED COMMENTS

•Multi-point benefits have been proven to be vastly superior to single point.

•Must be programmed to accommodate variable valve timing.

•Sequential paired injection: 1995=5%, 2000=20%. There is another system called "sequential paired injection," (inventors Bognen/Griffin) which is as cost effective as banked but has performance better than sequential.

•New emission standards may drive use of sequential for transient control improvement.

DISCUSSION

In recent years, bank switched multi-point fuel injection has been more commonly used than timed sequential systems. This is due, in part, to the relative ease of implementation and the relatively low output data rate for the engine control system. However, performance benefits can be achieved by sequential, timed fuel injection. There is a clear trend toward sequential systems.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers give identical forecasts for 1995. However, for the year 2000, the manufacturers forecast essentially 100% timed sequential and suppliers forecast only 80%, the remainder being programmable.

STRATEGIC CONSIDERATIONS

The V-type engines applications have continued strongly in U.S. production in spite of the forecast of a gradual shift toward in-line 4-cylinder engines during the period of severe fuel shortages. In fact, the recent general Delphi study shows a strong trend toward V-6 engines. The move toward sequential timed fuel injection is due, in part, to the demonstrated performance improvements relative to bank switched injection and to improved engine control system capability.

19. What percentage of NAPPV with spark-ignited engines will incorporate the following ignition systems in the years indicated?

	Median Response		Interquartile Range	
Ignition Systems	1995	2000	1995	2000
Distributorless ignition systems	50%	75%	45/50%	75/95%
Knock control/adaptive control	40	50	30/40	40/60
Individual cylinder control of ignition	10	30	5/10	20/40
Closed-loop timing (other than knock control)	10	30	10/20	20/40
Coil-on-plug control	10	25	3/10	20/30

Note the various categories above are not mutually exclusive so that individual columns do not necessarily add to 100%.

SELECTED EDITED COMMENTS

•This is hard to predict since engine layout influences coil-on-plug, detonation sensitivity influences knock control.

•Depends on cost reduction

•I expect processing to increase dramatically in the mid-90's, allowing more types of adaptive control to be used.

DISCUSSION

An electronic engine control system regulates fuel flow, ignition timing, and several other secondary variables. Earlier questions have explored fuel metering control technologies. This question considers a variety of technologies for ignition systems.

The panelists response indicate near consensus that DIS will replace the conventional system by the year 2000. The panelists are also enthusiastic about knock control but expect relatively low market penetration for other means of closed loop ignition control or for individual cylinder control of ignition timing.

Considerable performance benefits result from this technology. However, improvements in knock sensor technology and signal processing may make knock control even more effective. The panelists responses suggest a significant market penetration for knock control.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers give identical results for 1995 except for knock control, in which manufacturers forecast 10% less than suppliers. For the year 2000, the manufacturers forecast less in the following technologies than the suppliers (manufacturer/supplier percentage application): Distributorless ignition (75/80), knock/adaptive control (40/60), individual cylinder control of ignition (25/30), closed loop other than knock control (30/40), and coil on plug (25/20).

STRATEGIC CONSIDERATIONS

Each of the features above involves a technological improvement over traditional ignition systems. In the future competitive environment, many of these technological features may be demanded by the market as the public becomes aware of the vehicle performance benefits.

Perhaps the most significant new ignition system technology to achieve widespread success is the distributorless ignition system (DIS). The DIS avoids mechanical complexities of a distributor-based system and offers great flexibility for ignition timing (including individual cylinder control). Although a DIS system involves multiple coils, it still has cost advantages over a conventional distributor-based ignition system.

Another important ignition system, technology is knock control. In this system a sensor measures the intensity of engine knock. The control strategy involves advancing the ignition timing until excessive knock is produced. At this point the ignition timing is retarded. Such a system is currently used with turbocharged engines, which have a higher propensity for knock than normally aspirated engines.

The various electronic ignition system features studied in this question provide a variety of opportunities for suppliers. For example, there is considerable room for advancement in sensing and signal processing for knock measurements (partial or trace levels of knock). Such technology could be forced by tighter emission constraints or increases in current CAFE standards.

20. What new actuator technologies do you foresee will be required to improve engine/transmission performance? In what year do you expect to see their commercial introduction in passenger vehicles?

New Actuator Technologies	Year
Anti-noise systems	2000
Direct injection valve	2000
Electro-rheological (fluid i.e., actuators)	2000
Multiple fuel injection per cylinder	2000
Individual valve lifter	2000
Clutch	1995
Linear transmission actuators	1995
Smart power IC devices in conjunction with multiplexing	1995
Throttle actuator	1995
Torque modulation position	1995
Transmission gear shift with clutch	1995
Variable induction control solenoid	1995
Smart solenoids	1993
Variable swirl vanes	1991
Linear transmission hydraulic control	1990
Supercharger control	1989
Drive-by-wire actuator	1988

SELECTED EDITED COMMENTS

•I expect CVT is the next generation.

•Low cost solenoid valves, low cost injectors.

DISCUSSION

This open ended question has produced several interesting responses. A majority of the responses represent one form or another of very low cost linear-displacement actuators. Such an actuator would have many applications in integrated engine/transmission control systems including, for example, gear changing and throttle actuation. It is clear that there is a great market opportunity for such an actuator. However, the technological problems associated with such a development are non-trivial and relatively slow development can be expected.

STRATEGIC CONSIDERATIONS

There have been many linear actuators developed for various applications (e.g., aerospace, industrial process control, etc.). However, these devices have tended to be too costly or too large physically for automotive applications. There have, of course, been several automotive actuators in production (e.g., stepper motor actuator for idle speed control).

There will probably always be room for future development and refinement for automotive actuators. To be most useful in automotive applications, an actuator should have linear displacement, the flexibility to be designed and constructed for a variety of physical sizes, torque/thrust levels to fit many automotive needs, of fast response (e.g., 10-100 ms), and small power requirements. Of course, cost must be minimized and reliability maximized for any new actuator configuration.

Nevertheless, the desirability and marketability of such an actuator will likely motivate several R&D efforts to produce improvements in this important automotive component. There is a market opportunity for such a device.

21. What sensor developments or improvements do you foresee will be required to improve engine/drivetrain performance? What year do you expect to see commercial introduction of each?

Sensor Development/Improvement	Median Response	Interquartile Range
Cylinder pressure	1995	1995/2000
Exhaust gas chemistry	1997	1997/1998
Low cost, accurate mass airflow meter	1992	1992/1995
Torque	1994	1994/1995
Wide range O_2	1997	1997/1998

Selected Single Responses	Year
Integrated smart sensor	1996
Fluid pressure	1995
Hall-type probe sensors located in crankshaft	1995
Optical flame emission sensor	1995
Tire slip	1995
Transmission ratio	1995
High temperature Hall-effect $>200^{\circ}$ C	1995
High resolution-encoding	1994
Drive-by-wire position	1993
High resolution crank shaft sensor	1992

SELECTED EDITED COMMENTS

•To achieve major cost, size, and reliability improvements, there must be a trend to integrate several sensors and/or actuators into a single package. The associated electronics should also be part of the package.

DISCUSSION

At the present time, engine control strategy involves controlling fuel metering at stoichiometry and optimization of ignition timing for performance. This open ended question is intended to survey opinions about changes in engine/drivetrain which have the potential to improve performance in such areas as emissions, fuel economy, etc. The open ended question avoids constraining or biasing panelist responses, in the sense that each panelist can present a wish list for future technology. The responses of our panelists are ranked in order in the first table above. The majority of our panelists suggest that a cost effective cylinder pressure sensor is required to improve engine performance. Next in order is exhaust gas chemistry measurements including exhaust gas oxygen concentration. However, a sufficient number of panelists selected wide range O_2 sensor that we have displayed it as a separate category, as shown above.

STRATEGIC CONSIDERATIONS

Integrated engine/drivetrain control requires measurement of several variables for both the engine and transmission. As in the case of any control system, sensors play a crucial role in the successful implementation of an integrated driveline control system. The sensors listed by the panelists are capable of providing the required measurements. For example, a cylinder pressure measurement permits an estimate of load torque which is a primary variable along with angular speed for transmission control. Of course, cylinder pressure measurement is also useful for engine control.

There has been considerable research effort devoted to developing a cost effective durable cylinder pressure sensors as well as to developing a control strategy which is based upon measurement of this variable. Corresponding effort has been devoted to sensors for mass airflow, torque and wide range linear oxygen sensor. The literature includes many reports on this research. However, a key issue that remains is determining the relative benefits of the optimized system in relation to its costs.

III. INSTRUMENTATION/COMMUNICATION/NAVIGATION

22. What major new technological advances do you foresee in automotive instrumentation by the years indicated?

1995
Displays
•Electrofluorescent display. •Color LEDs with dot addressability or other flat panel display with low resolution graphics. •Electronic display contrast/readability equal to analog displays, more accurate sensors for earlier warning of failure/maintenance needs. •Graphic display for multi-purpose use. •Head-up displays, spread spectrum communication. •Low cost LCD. Diagnostic sensor improvements. •High contrast ratio LCDs, combination analog/digital clusters. •Reconfigurable screens. •Reformattable flat panel displays. •Virtual image, CRTs, project systems.
Diagnostics
•Better diagnostics, more systems status information. •Diagnostics and expert systems appearing in some designs. Navigation by dead reckoning--CD memory, map matching, and sophisticated use of voice synthesis. •Industry standard vehicle data link. •Less use of discrete telltales. •Lower cost communications. •More types and more sophistication of information available, especially diagnostics and "course of action" recommendation for driver. •Route guidance navigation, obstacle detection. •Voice activation. •Navigation technology for route guidance; cellular phones in over 10% of vehicles; maintenance/service information centers.

2000
Displays
•[Display which is] adaptive to each customer usage. Road condition reports. •Curved vacuum fluorescent tubes. •Flat panel color displays. •Flexible format/customer formattable displays. •Liquid crystal multi-color. •Reformattable flat panel display.
Sensors, Communication, Memory
•CD memories [will be] in use. Multiplexing will increase. •More external information displayed. •Multi-dimensional holographic display, digital satellite communication. •Navigation by satellite (global positioning satellite) input. Limited use of top IP done by heads up display. •Very sophisticated AI/expert systems for diagnosis. Sophisticated use of voice recognition--non speaker dependent. •Smart sensors. •Traffic/route guidance and advising. •Improved vehicle climate controls with features like solar load reduction, and his and hers temperature settings.

DISCUSSION

As in the previous question, this open ended question allows panelists to present novel concepts for future developments in instrumentation, communication, and navigation in passenger vehicles. We have listed the above responses in the order of the proportion to the number of panelists who have suggested each. The responses indicated that in the instrumentation area, the panelists all expect to see displays having more flexible format and content than present systems. Navigation combined with route guidance can be expected to evolve.

There are many interesting responses to this question which, in general, suggest highly flexible, multicolor display with alphanumeric and graphical capability. For example, in addition to messages and/or parameter values, future instrumentation systems (at the high end) will be capable of navigation (map) display along with route guidance.

STRATEGIC CONSIDERATIONS

The trends in modern society toward increased information transmission and display are reflected in projected future automotive instrumentation systems. The high level capability forecast for automotive instrumentation can provide advanced levels of driver information including, e.g., vehicle status, location, heading (navigation), and trip parameters. Some experimental driver information systems, which have been demonstrated, clearly shows advanced information capability compared with the present systems.

23. Which of the following technological advances in automotive instrumentation do you expect to see in production by the years indicated?

	Percent of respondents who listed the following technological advances	
	1995	2000
Head-up-display	80%	32%
Navigation system with map display	64	24
Multicolor LED display	56	20
Multicolor liquid crystal display	52	36
Vehicle system status	68	24
Reformattable flat displays	20	52
Virtual image displays	9	8
Curved vacuum fluorescent displays	12	52
Road condition reports	28	48
Voice activation of subsystems	28	40

SELECTED EDITED COMMENTS

- Many of these may be introduced as special features for special high-priced cars. General use in millions of cars will take longer.

- Several of the technologies are already in production.

- Forecast volumes may be wrong in some cases.

DISCUSSION

A relatively high percentage of panelists expect to see the following in widespread production by 1995.

Head-up-display
Vehicle systems status
Navigation system with map
Multi-color LED
Multi-color liquid crystal display

By the year 2000, the panelists expect production of reformattable flat panel display and curved vacuum fluorescent display systems. Relatively few panelists expect virtual image (holographic) display. Less than 50% of the panelists expect widespread production of voice activation of subsystems.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers agree to within 9% for all categories.

STRATEGIC CONSIDERATIONS

Virtually all of the items listed above have been under development in one form or another for various applications including automotive. The intent of this question is to evaluate the production future for the various technologies.

A few of the technologies have, in fact, already reached some level of commercial sales. For example, navigation incorporating a map display have been sold (ETAK). Moreover, head-up-display has been demonstrated at various automotive shows and conferences (e.g., SAE International Congress). Other items (e.g., virtual image display) have only been demonstrated in laboratories or in experimental systems (e.g., road condition systems).

Although the future commercial success of any given technology is difficult to predict accurately, our panelists are very well informed, well placed to make key decisions, and their opinions and forecasts are probably as accurate as at the present time.

24. What percent of NAPPV will incorporate purely solid state instrument panel display by the years indicated?

Median Response		Interquartile Range	
1995	2000	1995	2000
20%	50%	15/30%	25/60%

SELECTED EDITED COMMENTS

•Cost and reliability issues will inhibit faster incorporation.

•Includes all solid state driving pointers.

•This includes analog displays driven by electronics.

•This assumes all gauges would have a display like vacuum fluorescent or LCD.

DISCUSSION

This question surveys opinion on market penetration of solid state displays. The panelists' responses show that analog displays will continue to be used in automobiles for the remainder of this century. However, such displays will be driven by solid state electronic signal processing.

The forecast for purely solid state display technology is somewhat lower than anticipated based upon previous Delphi forecasts and upon the literature. There was great enthusiasm among the engineering community when solid state displays were first introduced. Customer responses seemed equally enthusiastic. The results of our survey indicate a cooling of the earlier enthusiasm expressed in previous general Delphi studies.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Both manufacturers and suppliers have identical forecasts.

STRATEGIC CONSIDERATIONS

Automotive instrumentation displays began as either mechanical, pneumatic/fluidic, or thermal devices. These devices were replaced by analog electromechanical displays as the latter became cost effective. For a period of time, some analog electromechanical displays were replaced by warning indicators which only alerted the driver if a problem occurred.

Modern electronic display technology, which we have chosen to represent by the term solid state, is so cost effective that it has been incorporated in automotive display systems. Some observers of the industry predicted that solid state display would replace analog electromechanical (and warning lamps). However, these predictions have been tempered somewhat by less than anticipated costumer response.

25. Of the NAPPV incorporating purely solid state instrument panels, what percent will use each of the following technologies by the year indicated? (NOTE: Some vehicles will use a combination of these technologies so the total is not necessarily 100%.)

	Median Response		Interquartile Range	
	1995	2000	1995	2000
Vacuum fluorescent	40%	35%	40/50%	30/50%
LED	1	2	0/2	0/5
Liquid crystal (w/lighting)	35	40	25/45	30/50
Cathode ray tube (CRT)	2	2	1/5	1/5
Solid state equivalent of CRT	1	5	0/3	2/10

SELECTED EDITED COMMENTS

•Voice activated and responding: 1% by 1995, 5% by 2000.

•Solid state controlled, analog movements.

•The R&D for television and PC's could result in a breakthrough which could significantly change auto display technology by the year 2000.

•Customer preference for analog movements will continue to be strong. Solid state driven analog displays: 1995=40%, 2000=25%. Significant new technology probably a factor by the year 2000.

•Need to separate out flat screen reconfigurable display by technology (VF,TFT-LCD, Plasma, and Electrofluorscent).

•Relative cost of various display technologies will play an important role in their selection.

•We haven't seen anything yet as far as the use of new LCD technologies.

DISCUSSION

We have used the term solid state to distinguish electronic display from electromechanical (or warning lamp) display. However, within the category of solid state display there are various technologies. This question surveys preferences for solid state automotive instrument panel display technology. The panelists' responses clearly show evolution from the present vacuum fluorescent technology to the other prominent choices.

Vacuum fluorescent displays have long been employed in automotive instrumentation/driver information systems. Although this technology will continue, with a gradual reduction from 1995 to 2000, it will still be used in a substantial portion of automotive display. The strongest competitor to vacuum fluorescent technology appears to be liquid crystal (particularly multicolor liquid crystal). The LED, which is widely used for display in consumer electronics, is expected to have a very low utilization in automotive display. The cathode ray tube is expected to play a minimal role in automotive instrumentation throughout the remainder of the century.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers agree to within 5%, except for vacuum fluorescent displays for the year 2000: manufacturers 50%, supplier 30%.

STRATEGIC CONSIDERATIONS

A vacuum fluorescent display, which has played a major role in automotive instrumentation, is a gas discharge technology. Fixed characters or segments of characters are created by fabrication of the individual gas discharge elements. Application of electric power to any particular element causes it to illuminate. In recent years, a relatively wide range of colors have become available.

The liquid crystal display is based upon a technology involving polarization rotation of light passing through a special (nematic) liquid. The liquid crystal display requires external lighting for visibility of the specific element. As in the case of vacuum fluorescent display, fixed characters or segments of characters are created.

One of the potential drawbacks to fluorescent or liquid crystal displays is the relatively limited flexibility of messages which can be displayed. Only those alphanumeric characters which can be represented by the available segments can be displayed.

On the other hand, a cathode ray tube CRT has enormous flexibility for message and even for graphic display (e.g., maps for navigation). However, CRT displays tend to be expensive by themselves and require special display electronic hardware and software. Moreover, a CRT is potentially susceptible to damage and is potentially dangerous in impact (implosion) situations.

There are a number of solid state displays currently available or under development which are functionally equivalent to the CRT. Assuming the cost of such a solid state display can be reduced, it can provide a strong competitor to the CRT which has already been shown to have great capability in automotive instrumentation.

26. What percent of NAPPV will utilize multiplexing in the following subsystems?

	Median Response		Interquartile Range	
	1995	2000	1995	2000
Door interfaces for power controls (power windows, seats, door locks mirrors, etc.)	10%	30%	5/20%	20/60%
Lighting controls (headlamps, tail lights, turn signals, and other interior lighting)	5	20	3/10	10/40
Steering column wiring	10	25	5/20	10/50
Entertainment	5	20	1/15	10/30
Vehicle information/instrument panel (IP) functions	20	40	5/30	25/70

Other:
Connection with engine controls: 1995=30%, 2000=90%.
Control subsystems communication (i.e. engine/chassis): 1995=5%, 2000=30%.
Diagnostics: 1995=5%, 2000=15%.
Engine to body computer: 1995=100%; 2000=100%.
Class A bus for some switches: 1995=20%; 2000=85%.
Powertrain: 1995=10%, 2000=50%.
Sharing slowly changing sensor data e.g., coolant or ambient temperature.

SELECTED EDITED COMMENTS

•Entertainment multiplex includes standard data link from controls to receiver.

•Lack of cost effective smart power in foreseeable future.

•The above assumes a combination of low speed (Class A) and higher speed multiplex systems.

DISCUSSION

Multiplexing in automobiles is a much discussed technology which has been somewhat slow in coming. It has been suggested that multiplexing systems will evolve in automobiles, appearing in limited applications in certain subsystems. Then, as cost effectiveness of multiplexing improves, there will be increased applications in the entire vehicle.

This question surveys opinions about multiplexing market penetration as a replacement for the wiring harness in selected subsystems. Other applications are also prime candidates for multiplexing as suggested by comments (e.g., inter-system communication).

Other aspects of multiplexing such as class, speed, protocol, etc., are clearly relevant, but are beyond the scope of the present study.

The responses to this question support the notion that multiplexing will be introduced as a partial system and will gradually evolve to make up an increased fraction of the vehicle wiring harness.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Both manufacturers and suppliers forecast nearly identical multiplexing market penetration through 1995. However, for the year 2000, the manufacturers forecast 20-40% higher market penetration for these multiplex subsystem than the suppliers.

STRATEGIC CONSIDERATIONS

For virtually the entire history of the automobile (with very few exceptions, (such as experimental cars), the inter-connection of all electrical or electronic devices and systems has been by means of wires in so-called wiring harness. For any given automobile, the sudden rise of automotive electronics has greatly increased the complexity, weight, and cost of the wiring harness.

Multiplexing offers the potential to replace the existing harness with a few wires. Typically, an automotive multiplex system consists of a wire for carrying power to each electrical component (e.g., motors or lights) and a separate wire linking a controller with a special coded receiver for each switched load. By transmitting a unique code to a given receiver, it is possible to switch on or off related electrical device. In this way a very complex heavy and expensive wiring harness which is presently used for switching electrical devices is replaced with a pair (or at most 3) wires. Considerable savings in weight is thereby possible with multiplexed systems. Similarly, the wiring required to send signals from one electronic subsystem or component to another can be replaced by a multiplex link. The savings in weight and harness complexity provided by multiplexing are strong motivations for its introduction. On the other hand, the cost/benefit for multiplexing has not quite reached the point where using it to replace the wiring harness is justified.

27. What percentage of multiplex systems will use the following techniques for the control bus by the years indicated?

	Median Response 1995	Median Response 2000	Interquartile Range 1995	Interquartile Range 2000
Twisted pair	60%	50%	50/80%	40/70%
Wire control bus	20	25	10/40	20/40
Fiber optics control bus	0	10	0/1	5/15

SELECTED EDITED COMMENTS

•All multiplex will tend to conform to SAE standards.

•Assume wire control bus means shielded twisted pair or coax.

•Fiber optic includes any use of data transmitted by light modulation.

•High percentage for fiber optics because of high percentage of steering column control which needs fiber optics--short run, tight space.

•With sophisticated software approaches to virtually eliminate the adverse effect of electrical noise (EMC/RFI), conventional wiring will dominate as the most cost effective technique.

•Coaxial cable.

DISCUSSION

When used for control or power switching applications, a multiplex system consists of a power bus (i.e., connected to vehicle electrical power system) and a control bus. The control bus sends coded messages to receiver units. The receiver unit for any electrical subsystem decodes messages which are sent on the control bus. Whenever the code appropriate for a given electrical subsystem is received, the receiver activates the relevant subsystem.

There are various technical choices for the control bus including: twisted pairs of wires, coaxial cable or shielded wires which we have called wire control bus, and fiber optic buses. This question surveys preferences for control bus configuration. The twisted pair is the preferred choice of the panelists throughout the remainder of this century, with wire control bus as a second choice. This latter choice includes single wire with vehicle ground, untwisted pair, and coaxial cable. The fiber optic control bus will not have much utilization until the next century. It should be noted that the totals differ from 100%, presumably because the panelists had other configurations in mind than those listed.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers agree to within 5%.

STRATEGIC CONSIDERATIONS

The previous question introduced the concept of a control bus for a multiplexing system. This bus provides the electrical path over which coded signals transmit commands to the multiplex receiver, or over which data is transmitted in time domain multiplex. The control bus should have high immunity to electrical noise to prevent accidentally activating any given receiver or to avoid contaminating transmitted signals.

A number of choices are available to the system designer. Perhaps the best control bus is a coaxial cable. The outer shield eliminates coupling of noise into the inner coaxial wire. However, coaxial cables tend to be too expensive for automotive applications. A potential alternative to coaxial cable is the twisted pair conductor. A pair of wires are actually twisted around one another. Coupling of external electrical noise is nearly perfectly cancelled for such a system. Although the cost of twisted pairs is less than for a coaxial cable, its noise immunity is less than a coaxial cable.

A third alternative control bus is a fiber optic cable. This system is advantageous from the noise immunity and weight standpoint relative to the other two choices. However, fiber optic cable systems are typically very much more expensive than the other two alternatives. Furthermore, the device required for coupling optical cables to a receiver is also an expensive mechanism.

28. What percentage of NAPPV will have Head-Up Display (HUD) in the years indicated?

Median Response		Interquartile Range	
1995	2000	1995	2000
3%	10%	1/5%	5/20%

SELECTED EDITED COMMENTS

•Very costly optics.

DISCUSSION

The panelists foresee a gradual increase in use of Head-Up-Display (HUD) throughout the remainder of this century. However, the median forecast for even the year 2000 suggests limited market penetration. Furthermore, the relatively large interquartile range indicates uncertainty in the future for this technology.

One reason for low projected market penetration is the relatively high cost of the system optics. An opportunity exists for HUD, provided that the system cost can be reduced significantly. However, there is no clear and compelling belief that HUD has the strong perceived customer benefit required to offset the negative impact of high cost on market penetration.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The responses for manufacturers and suppliers were nearly identical for both years.

STRATEGIC CONSIDERATIONS

Head-up-display has been widely used in aircraft applications, where cost is relatively unimportant. The system consists of a partially reflecting mirror which is placed in the pilot's (driver's) line of sight for normal flying (driving). Important information (e.g., navigation or aircraft altitude, speed, RPM, fuel, turn indicators, etc.) is projected on this mirror. The pilot (driver) can read or monitor this information without moving his eyes from the forward view through the windshield.

29. Do you foresee the appearance of voice recognition for driver input to the vehicle? If yes, please indicate what year.

		Median Response	Interquartile Range
Yes:	79%	Year: 1995	1994/2000
No:	21%		

SELECTED EDITED COMMENTS

•1995: speaker dependent, 2000: speaker independent.

•Already available for telephones.

•Cellular telephone dialing.

•No, except for cellular phone input--with hands free headset.

•Hands-free telephone must be speaker independent.

•I suppose some fringe will have it, but really, who wants to talk to a car?

•Initially as a gadget but eventually to eliminate clutter for convenience features (e.g., remote window and lock controls).

•Will be available first on cellular phones in 1989 or 1990. Other automotive applications will develop by 1993-1994, assuming favorable acceptance.

DISCUSSION

A majority of panelists (79%) expect to see voice recognition as a driver input in the foreseeable future. Of those who expect voice recognition to be introduced, the majority expect it to first be applied to cellular phone dialing. This is a reasonable supposition because the present method of dialing is potentially distracting to the driver and arguably dangerous.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Essentially 80% of both manufacturers and suppliers respond that they do expect voice recognition for driver input to the vehicle. Of those responding yes, the manufacturers expect to see introduction about one year later (1996) than suppliers (1995).

STRATEGIC CONSIDERATIONS

Voice recognition is an aspect of the artificial intelligence branch of computer science. Considerable research has been conducted (and is ongoing) and much progress has been made in this area.

One of the problems for voice recognition is that the system is typically speaker dependent. That is, the system "learns" to recognize a specific speaker. Any change in speaker leads to some erroneous responses. One very costly and undesirable solution to this problem is "train" the vehicle electronics to recognize a particular driver.

There are presently commercially available packages which are capable of voice recognition for a specific speaker and for a limited well/defined vocabulary. This level of technology is costly but available for automotive application. It is highly likely that cost effective speaker independent voice recognition will be developed for commercial automotive applications by 2000.

30. Which of the following technologies do you foresee will be most likely to provide cost effective rear visibility improvement and by what year will it become commercially available? *NOTE: Data represents percent of respondents who chose each category.*

Rear Visibility Technologies	Percent of Respondents		Median Response	Interquartile Range
	No	Yes	Year Most Likely	
Video system	38%	62%	2000	1997/2000
Improved mirror system	50	50	1994	1991/1995
Use of fiber optics	90	10	1995	1995/2000

SELECTED EDITED COMMENTS

•Due to potential of being lower and more reliable (due to its passive nature), fiber optics, with the appropriate lenses, is most likely. Driving force might not be to greatly improve visibility but rather to make removal of external mirrors possible for improved aerodynamics and wind noise.

•Rear sonar, most likely in 1991.

•The driving factor will be the importance of aerodynamics.

•The improvements in mirror system are ongoing.

•A major breakthrough is needed. None appear to be on the horizon.

DISCUSSION

The panelists are evenly divided about near term improvements in mirror systems. The video system is preferred slightly over mirrors by a majority of panelists by about 2000. Improved mirror systems have received a somewhat less enthusiastic response from the panelists. The use of fiber optics received surprisingly little enthusiasm in spite of its potential superiority to mirrors with respect to geometrical limitations.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The responses for both manufacturers and suppliers were nearly identical for all categories.

STRATEGIC CONSIDERATIONS

Rear vision systems provide the driver of a vehicle with a view immediately behind that passenger car or light truck; such a view can readily be obtained using relatively simple mirror systems. For large vehicles (e.g., vans), a suitable mirror system may actually be more costly than a video system. A video system for the automotive environment will likely benefit from the technological evolution of solid state video cameras, and displays which are potentially cheaper than the corresponding present-day vacuum tube video systems. Some of the miniature solid state T.V. technology from Japan is potentially applicable to a rear video system.

Mirror systems for rear visibility require open line-of-sight between the various mirrors for light propagation. This requirement is relatively restrictive from the standpoint of vehicle geometry. Although fiber optics can circumvent this restriction, the use of fiber optics will probably be more expensive than mirror systems.

31. What is the likelihood that standards for automotive serial communications links will be developed by the years indicated? *NOTE: Values given are percent of respondents who selected each choice.*

	1995	2000
Extremely likely	3%	4%
Likely	9	4
Possible	21	14
Unlikely	32	14
Highly unlikely	35	64

SELECTED EDITED COMMENTS

•Assumed here as SAE driven standards or accepted practices, not de facto standards. I believe a de facto standard will exist in 1997 if SAE is not successful.

•Likely by 1992.

•There is limited motivation for standardization by the major OEMs.

•It is clear that U.S. standards will be a reality by 1995. However, the automakers will likely also use other protocols for special needs.

DISCUSSION

The panelists suggest that the development of standards for serial communication links to passenger vehicles is unlikely to highly unlikely by the year 1995. If such standards are, in fact, not achieved by 1995, there is even less likelihood for their introduction for the remainder of the century.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Both manufacturers and suppliers agree that these standards are unlikely but the manufacturers are a bit more confident than the suppliers of this position.

On the other hand, standards for serial communications links are very specific to individual manufacture electronic design configurations. Such specificity tends to preclude standardization and perhaps explains the panelists responses.

STRATEGIC CONSIDERATIONS

The increasing application of digital electronics in automobiles has increased the need for intercommunication between on-board systems. For example, the engine control system provides data for the vehicle instrumentation (i.e., driver information system).

Automotive digital systems operate in such a way that a serial link provides a suitable communication channel between systems. In a serial link, data is sent sequentially along a single (or double) wire cable system. The data is necessarily synchronized and is transmitted with a specific format or protocol.

Standardization of such communication links has several potential advantages. For example, diagnosis and repair would be possible using a standard technician's instrument. There has been considerable movement towards automotive communication standards in SAE committees. Should the SAE committees fail to reach a recommended standard, there may be governmental intervention. At the present time it seems possible that some level of standardization will be achieved for certain electronic systems (e.g., engine diagnostics), although the panelists are skeptical that universal standards will be achieved for other on-board systems.

32. By what year is it likely that standard serial communication links will be developed or adopted by U.S. manufacturers?

	Median Response	Interquartile Range
Year:	1994	1988/1995
Never:	20%	

SELECTED EDITED COMMENTS

- A global standard must be developed!
- J 1850 for medium speed mid-to-late 1990's not necessarily "exactly the same" by each manufacturer.
- Might want to go after types, levels, and speeds of links.
- We may have agreement by 1992 for implementation by 1994-1995.

DISCUSSION

A majority of our panelists (80%) expect some standards to be developed for serial communication links. The expected time for this development is about 1994. However, 20% of our panelists do not ever expect to see such standards.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The majority of both manufacturers and suppliers forecast that standards for serial communication will be developed or adopted by 1994. Only a small percentage of either group said that these standards would never be adopted.

STRATEGIC CONSIDERATIONS

The increased integration of electronic subsystems is increasing the trend toward serial data communication links within a vehicle. A similar trend has occurred in other electronic applications such as electronic instrumentation and computer systems. For those systems, standards have been developed (e.g., RS232) which facilitate implementation of large systems. The standards include common hardware and standard communication protocol.

Although there is less motivation for such standards in the automobile industry than in the computer industry, we have attempted to survey opinions of our panelists regarding standards. For applications such as universal diagnostics "scanner" there are benefits to having standards such as are evolving through SAE J1850. For on-board inter-system-communications, there is perhaps less need for standards than for the diagnostic function.

33a. What percent of NAPPV will be equipped with navigation systems in the years indicated?

Median Response		Interquartile Range	
1995	2000	1995	2000
2%	10%	2/5%	5/10%

SELECTED EDITED COMMENTS

•The low estimates are based on limitations of systems cost versus alternatives and lack of development of 1) map data bases, 2) data base standardization, and 3) cost, technology, and sensing of external reference systems (i.e., GPS, Loran, signpost).

•Future of navigation systems is tied to traffic control which relies on government involvement.

•Rental car possibility.

•Until location specific traffic-on-road information is available, the benefit is small compared to cost, except for rental car customers in strange locations.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers differ by no more than 3%.

33b. Of those vehicles having on-board navigation systems, what percent will use the following sensor method in the years indicated?

	Median Response		Interquartile Range	
	1995	2000	1995	2000
Satellite	5%	30%	0/7%	20/30%
Ground based radio (e.g. Loran)	0	0	0/2	0/10
Dead reckoning	85	50	70/95	40/70
Signpost	0	0	0/0	0/5

SELECTED EDITED COMMENTS

•Active: 1995=5%, 2000=30%(GPS/Loran). Passive: 1995=5%, 2000=20%(maps).

•Passive information, 1995=30%.

•All navigation systems will need dead reckoning for primary or secondary input. GPS technology is too expensive. Loran C is limited in accuracy.

•Increased accuracy will drive toward absolute system (not dead reckoning). Signpost requires too much public investment in most areas.

•Inertial navigation and signpost.

•Map matching. A combination of dead reckoning and something else will be used.

•Some form of dead reckoning technology could be used in all year 2000 navigation systems. Dead reckoning could supplement other sensing technology which may not be available in rural areas or could be ineffective in cities with tall buildings, etc.

•Driver updating.

DISCUSSION

Although electronic navigation aids have achieved a high level of performance and market penetration for aircraft and watercraft, similar progress for automotive applications has not yet been achieved. Of course, one of the reasons for this lack of progress is the relatively high cost of navigation systems relative to acceptable automotive cost.

Nevertheless, there is some market potential for automotive navigation systems (e.g., for fleet vehicle or niche vehicle application). This question surveys the potential market penetration and some of the technology which is applicable.

At the present time, the panelists have relatively little enthusiasm for radio based automotive navigation. Rather, the consensus seems to strongly favor dead reckoning methods, including electronic signal processing such as map correlation, for position fixing or precise updating of information.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers agree to within 2% except for the use of dead reckoning: for 1995, manufacturers forecast 80%, and suppliers 90%; and for the year 2000, manufacturers forecast 50%, and suppliers 65%.

STRATEGIC CONSIDERATIONS

The commercial introduction of automotive navigation (e.g., Etak) has provided an interesting environment for assessing market potential. Although the sales have been somewhat slower than hoped and anticipated, this is perhaps not atypical for a new technology and application. Early users include commercial fleet vehicle operators, for which the benefits of automotive navigation are readily apparent.

Many panelists have suggested, and it has been suggested in the literature, that coupling navigation to a route guidance or driver information system would greatly increase the utility (as well as sales) of navigation systems. The technology for such coupling exists and has been demonstrated experimentally. However, the infrastructure for widespread route guidance in the U.S. is (at best) several years in the future. These observations are consistent with the relatively low forecasts for navigation system market penetration. The choices for automotive navigation sensors are clearly distinguishable with respect to performance, complexity, and cost. Although satellite sensors have demonstrated high performance, they are costly and relatively complex. By contrast, a dead reckoning system typically utilizes one (or more) wheel speed sensor(s) and possibly a magnetic compass for heading. Such a sensor configuration, though having far less long term accuracy, is relatively inexpensive. Deficiencies in performance or accuracy can be compensated, in part, by such signal processing methods as map matching. In this scheme, the navigation system contains the coordinates of all roads within a given region. The vehicle is assumed to be on the road at a point nearest the current estimated position and thus position is indicated on the display. Updates to position are facilitated by maneuvers such as turns.

IV. CHASSIS (Suspension, Handling, Motion Control)

34. What technological advances are required to broaden the application of electronic suspension systems?

50% of respondents listed the need for lower cost of sensors, actuators, or entire systems.

REPRESENTATIVE SAMPLE OF OTHER TECHNOLOGICAL ADVANCES

•A basic understanding of the complex dynamics must be achieved with computer models to effectively conceive optimum control strategies.

•Active powerful actuators.

•Modest improvement in suspension/steering models.

•Energy management and customer awareness.

•Hybrid micro-circuit. Fast actuating variable flow valve.

•Improvements in actuator technology, specifically broadening range of functionality while holding costs in line.

•Road roughness sensing, adaptive control method using a model, and electronically controlled hydraulic actuator.

•Rugged chassis position sensor.

•Sensor/actuator robustness.

•New systems configuration approaches which achieve better performance and reliability through effective systems interaction with powertrain, steering, and braking systems.

•Servo-hydraulic systems, servo-valve development, multiplexing, ground sensing, accelerometers.

DISCUSSION

There are really several critically important technical problem areas associated with electronic suspension. As expected, the majority of panelists have identified cost (particularly sensor and actuator cost) as a major obstacle to widespread use of electronic suspension systems. However, there is a strong indication from many panelists that the modeling of the complicated vehicle dynamics is yet to be done to the level required for development of a reliable system. Nevertheless, the potential payoff for such a system is likely to motivate further development. Several interesting technical areas have been identified above by panelists, each of which provides opportunities for suppliers having a competitive solution to specific identified problems.

STRATEGIC CONSIDERATIONS

Electronic suspension systems have several potential performance benefits for passenger cars and light trucks. Through active control of suspension system parameters, it is possible to modify both ride and handling for the vehicle. A typical electronic suspension system has sensors for measuring relative displacement and/or acceleration of unsprung mass in relation to sprung mass.

The actuator typically modulates the viscous damping within a shock absorber to alter the suspension characteristics. Significant improvements have been demonstrated experimentally.

The development of advanced electronic suspension tends to be influenced by several factors: the nonlinearities in actuator performance, complexity in the modelling of the vehicle and suspension system dynamics and cost effectiveness of sensor and actuators. The influence of vehicle dynamics during maneuvering must also be included in the overall modelling process.

Nevertheless, there is considerable R&D effort toward active suspension and this technological development is expected to achieve the roughly 30-50% market penetration as forecast in question 2.

35. Rank order the following factors with respect to inhibiting the widespread commercial use (30,000+ units) of active suspension on cars produced in North America (1=most inhibiting factor, 8=least inhibiting factor). *NOTE: Values given are percent of respondents who selected each choice.*

Active Suspension Inhibiting Factors	Ranking 1	2	3	4	5	6	7	8
Total system cost	57%	23%	13%	4%	3%	0%	0%	0%
Reliability	0	29	18	32	14	4	3	0
Sensor technology	4	11	19	19	26	15	3	3
Actuator technology	21	17	21	17	14	7	3	0
Sensor cost	0	14	18	18	14	22	14	0
Control strategy	4	4	4	8	8	32	36	4
Liability	4	4	17	4	17	8	29	17

SELECTED EDITED COMMENTS

- Customer perceived value ranks 1.

- Value to customer ranks 3.

- Actuator/fail soft package requirements ranks 4.

- High speed networks ranks 6.

- Total system weight.

- System modeling ranks 1.

- Active and adaptive suspensions must be lower in cost and demonstrate value to the customer. With some of today's switched suspensions, customers cannot tell the difference between sport and luxury.

- Liability should not be an issue as long as there is a mechanical back-up with driver warning.

- Power consumption.

- The benefit is very high for luxury/high-end vehicles, hence cost is not primary issue.

- To be truly cost effective, distributed control must be in place to share sensor information from other electronic systems. Actuators are key for cost effectiveness also.

DISCUSSION

This question is strongly coupled logically to the previous question. However, this question is intended to order a restricted set of factors as they influence electronic active suspension. It is not surprising that total system cost ranks first by a wide margin in the view of most panelists as the most limiting factor. Reliability appears to be a second ranking factor but this choice is not clear cut.

Of the other factors, there is no clear choice for ranking third through sixth. Curiously, the panelists seem to feel that control strategy and liability are low ranking factors. Some of the control strategies which have been discussed in the literature are very complicated and are based upon system models which do not yet seem to have been validated. To take full advantage of the potential benefits of electronic suspension, considerable R&D will have to be done before effective control strategies can be formulated.

STRATEGIC CONSIDERATIONS

An automotive electronic suspension system consists of various sensors, electronic control module(s) and actuators (shock absorbers with variable displacement damping or spring rate). Each of these components contributes to total system cost (as well as the R&D effort, of course). Of these components, the sensor and actuators provide the most serious challenges for cost reduction. It can well be expected that system cost, which the panelists believe the most limiting factor for electronically controlled suspension, will be strictly paced by sensor and actuator costs. The cost for actual hardware for electronic control is typically not as challenging to reduce as the sensor and actuator cost. The software costs, though significant, are normally part of the development cost and will be a less significant factor if sufficient market develops to amortize these costs.

36. Please rank the following factors with respect to inhibiting the widespread applications (30,000+ units) of electronically-controlled electric power steering for the years indicated. (1 = most important, 8=least important) *NOTE: Values given are percent of respondents who selected each choice.*

1995								
Power Steering Inhibiting Factors	Ranking 1	2	3	4	5	6	7	8
New, low cost sensors	0.0%	5.6%	5.6%	11.1%	44.4%	33.3%	0.0%	0.0%
Control strategy needed	0.0	5.9	5.9	5.9	29.4	29.4	23.5	0.0
On-board diagnosis needed	5.9	0.0	0.0	5.9	11.8	23.5	52.9	0.0
New, low cost actuators	21.1	0.0	21.1	47.4	5.3	0.0	5.3	0.0
Liability	31.8	13.6	27.3	4.5	4.5	0.0	4.5	13.6
Reliability	12.0	52.0	12.0	12.0	4.0	8.0	0.0	0.0
System cost	37.0	25.9	29.6	3.7	0.0	0.0	3.7	0.0
None of the above	25.0	0.0	50.0	25.0	0.0	0.0	0.0	0.0

2000								
Power Steering Inhibiting Factors	Ranking 1	2	3	4	5	6	7	8
New, low cost sensors	0.0%	6.3%	6.3%	12.5%	43.8%	25%	6.3%	0.0%
Control strategy needed	6.7	0.0	0.0	13.3	33.3	33.3	13.3	0.0
On-board diagnosis needed	0.0	6.7	6.7	6.7	6.7	13.3	60.0	0.0
New, low cost actuators	11.8	5.9	23.5	41.2	11.8	5.9	0.0	0.0
Liability	38.9	11.1	27.8	0.0	0.0	0.0	5.6	16.7
Reliability	30.0	45.0	10.0	0.0	0.0	10.0	5.0	0.0
System cost	25.0	29.2	33.3	8.3	0.0	4.2	0.0	0.0
None of the above	50.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0

Other:

Customer perceived value: 1995=1; 2000=1
Customer perceived value: 1995=4; 2000=3
High speed networks: 1995=4; 2000=4
System modeling: 1995=1; 2000=1
Interface with powertrain control
Customer acceptance

SELECTED EDITED COMMENTS

•Liability should not be an issue as long as there is a mechanical back-up with a driver warning.

•Electric power steering is in competition with electronically modified hydraulic (reliability advantages).

•For new low cost actuators, assuming electric power assistance, not steer-by-wire. Liability: assuming steer-by-wire.

•Performance.

•Year 2000 is difficult to predict due to today's fast rate of technological development and rapid liability cost increases.

DISCUSSION

Although there is no clear cut ordering, it would appear that the three most important factors in the near term are: system cost, reliability, and liability. The need for new, low cost sensors and actuators rank about fourth and fifth thru 2000. The primary concern by 2000 appears to be customer perceived value. This suggests that the panelists believe technical problems will have been overcome and that marketing issues will affect widespread application of electronic power steering.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The top choice for manufacturers for both 1995 and 2000 is system cost, whereas for suppliers the most limiting factor is perceived to be liability. The second and third choices for both groups are nearly the same and are reflected by the tables above.

STRATEGIC CONSIDERATIONS

There are several potential benefits for electronically-controlled electric power steering. For example, electric power steering potentially has reduced power consumption relative to hydraulic systems. Moreover, it is relatively straightforward to program variable rate and variable "feel" steering as a function of operating condition. However, to achieve widespread commercial use, customer perceived benefits must be clearly visible, the system must be reliable and fail safe, and actuator cost must be reduced.

37. What are the major factors limiting widespread use (30,000+ units) of drive-by-wire?

Drive-by-wire Inhibiting Factors	Percentage of respondents who listed this factor
Liability	50%
Reliability	44
Cost	38

SELECTED OTHER FACTORS GIVEN

•Benefits vs. risk.

•Control system strategy with fail soft.

•Customer need.

•Fail-safe system backup.

•Lack of customer acceptance.

•Confidence among technological community.

•Lack of a fault-tolerant strategy.

•Replication of "feel" that drivers expect.

•Logistical constraints of interstate highways.

DISCUSSION

There are several potential performance benefits for a drive-by-wire system, particularly in vehicles equipped with electronically-controlled transmissions. In such a system, optimization of engine/drivetrain performance (e.g., torque, fuel economy) can yield performance and/or fuel economy benefits. However, any drive-by-wire system has safety risks and must be highly reliable and failsafe. The panelists responses clearly indicate the liability and reliability concerns. System cost is a third ranking factor for inhibiting widespread use of drive-by-wire. The other factors listed above were single responses of the panelists.

STRATEGIC CONSIDERATIONS

In a drive-by-wire system, the throttle is controlled electronically, rather than by means of a mechanical link from the driver pedal. There has been considerable discussion in the recent literature about improvements in fuel economy resulting from optimum electronic control of engine and transmission.

Drive-by-wire is a system, which directly affects vehicle safety and must be reliable and absolutely failsafe. Even for a highly reliable drive-by-wire system, the liability risks are considerable, whether perceived or real. Considerable attention has been given recently by the press to so-called "sudden unintended acceleration." Given such media exposure, potential customers might have to be shown significant potential benefits to choose such a system. Hence, the problem of perceived customer value in the light of significant liability risk may inhibit widespread commercial success for drive-by-wire.

38. What percent of NAPPV will be equipped with the following features in the years 1995 and 2000?

	Median Response		Interquartile Range	
	1995	2000	1995	2000
Anti-lock brakes (ABS)	35%	75%	25/50%	60/95%
Traction control (anti-spin)	10	40	5/25	20/60

SELECTED EDITED COMMENTS

•ABS is cost effective.

•ABS will become the "state of the technology" by 2000. Vehicles produced without it will subject OEMs to potential competitive and liability problems. Traction control will be an option by geographic area where it is important and on performance oriented vehicles.

•System cost will be major inhibitor to ABS, especially in economy car classes.

•Traction control will be a function added to basic ABS control but with input from engine and suspension modules.

DISCUSSION

This question has combined anti-lock braking with traction control because the technology for achieving these two functions strongly overlaps. Anti-lock braking will achieve a very high market penetration by the end of this century. Traction control is forecast to have roughly half the long term market penetration.

The interquartile range for traction control is somewhat greater for ABS, indicating slightly less consensus in the forecast.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Both groups had essentially identical responses.

STRATEGIC CONSIDERATIONS

Anti-lock braking (ABS) is an electronic system which actually controls brake pressure. Typically an ABS system consists of a wheel speed sensor, an electronic control unit, and an electrically-actuated brake pressure release valve. Whenever wheel speed deceleration during braking maneuver exceeds a specified threshold (tending toward incipient lock-up condition), the brake pressure is momentarily released. The system will maintain tire road slip as near to optimum as possible. The technology for ABS is relatively mature and continues to evolve with refinements.

Traction control can be achieved using some components from an ABS system. In at least one scheme, whenever one drive tire is detected to be slipping, a partial activation of the brake on that side can correct the slip. Of course, in a drive-by-wire system, engine torque could be automatically reduced to control wheel slip if both drive tires were slipping. Consequently, integration of various systems can simultaneously implement ABS and anti-skid.

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

	No	Yes	Median Response Year	Interquartile Range Year
Passenger cars	48%	52%	2000	1995/2002
Light trucks	42%	58%	2000	1995/2005

SELECTED EDITED COMMENTS

•Insurance pressures will push the government to regulate.

•Memory of heavy truck fiasco of the 1970's makes it unlikely.

•No need: customer demand will drive standard usage.

•OEMs will make ABS standard to support customer demand, maintain competitive products, and avoid comparative product liability problems. Regulations will not be required.

•The government is not inclined to force features which are gaining acceptance at a reasonable rate.

•Very cloudy, may depend on which party wins presidential election in 1988.

DISCUSSION

The issue in this question involves governmental regulations and requirements for anti-lock braking systems (ABS). The previous question shows strong market penetration for ABS. Slightly over half the panelists believe this trend will result from regulation. The motivation for ABS will more likely come from other factors, including customer demand. However, as the panelists are nearly equally divided on the issue of government intervention, this question has no clear cut prediction.

On the other hand, if market forces have not brought about ABS on the majority of vehicles by 2000, then the pressures on the government by, for example, the insurance industry to regulate ABS, may force such legislation.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The percentages for both suppliers and manufacturers agreed to within 3% for passenger cars and light trucks. However, the suppliers expected regulation for ABS by the year 1995 for cars and 1998 for light trucks. The manufacturers predict the year 2000 for both vehicle types.

STRATEGIC CONSIDERATIONS

The panelists are about equally divided on this issue, which suggests that there is far from a consensus. Although there is general agreement that ABS will achieve widespread utilization (see previous question), the issue here is whether this utilization will occur due to governmental intervention or market forces.

Many of our panelists believe that the governmental regulations will only occur if ABS is not being implemented by customer demand. Other factors affecting implementation are potential product liability problems. Any automobile manufacturer not offering standard ABS will likely suffer product liability losses in relationship to others having standard ABS.

V. ELECTRICAL/ELECTRONIC TECHNOLOGY

40. Assuming new electronic technology will need to be developed (either by OEM or supplier), what percent of each category below will be developed by the supplier for production application in the year 2000?

Category	Median Response	Interquartile Range
Sensors	80%	80/90%
Actuators	80	60/90
New electronic systems	20	10/50
Integrated circuits	80	50/90
Switches	90	80/100
Connectors	80	50/90

SELECTED EDITED COMMENTS

- Actuators are most application specific and hence most likely to be OEM developed.

- Control systems, diagnostic, and fail softs will be designed and specified by OEMs.

- Development being moved from OEM to supplier.

- Supplier does not include OEM component divisions.

DISCUSSION

This question is intended to explore the OEM/supplier division for development of new electronic components. Traditionally automotive OEMs purchase standard components (e.g., wiring switches, standard ICs). However, they tend to make, or at least have some capability to make application specific components (e.g., custom ICs, sensors, and actuators). Development of new technology for application on specific vehicles has, in the past, been largely performed by automotive manufacturers. For example, new sensors and actuators for engine control have typically been developed by the OEM or an allied division. Custom integrated circuit design have often been OEM efforts in conjunction with a supplier of an allied electronic division. The panelists' responses indicate a shift to very high percentage by supplier-developed integrated circuits.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Manufacturers and suppliers were identical to about 4% for all categories except new electronic systems. For this latter category only 10% of manufacturers expect supplier development whereas 50% of the suppliers forecast supplier development.

STRATEGIC CONSIDERATIONS

The panelists suggest that the OEMs can be expected to retain control of, and will pursue development, of new electronic systems. However, it is also clear that suppliers must take much of the burden of development of new sensors, actuators, integrated circuits, switches, and connectors. The relatively high percentage of panelists who forecast supplier development of sensors and actuators indicates a shift from OEM development.

Generally, in the future, suppliers will be expected to carry a larger fraction of the R&D burden for new technology. Manufacturers can be expected to take system responsibility and to coordinate newly developed components into the relevant system. The supplier must of course have the necessary engineering personnel with experience in the relevant technologies as well as R&D facilities. CAD/CAM capabilities can be expected to facilitate the interface between the supplier and the automotive manufacturer. The cooperative relationship required for joint development demands also open communication between the supplier and OEM engineering.

41a. What is the likelihood of the introduction of 32 bit microprocessors in automotive applications by the year indicated?

	1995	2000
Extremely likely	13%	0%
Likely	19	12
Probable	33	13
Unlikely	19	34
Extremely unlikely	16	41

SELECTED EDITED COMMENTS

•Custom devices (microprocessor) will continue to dominate. More likely to go RISC than 32 bit.

•Introduction means more than 30,000 units.

•The possible need for redundant controls to enhance reliability and supply "limp-home" capability would require smaller, less costly machines handling fewer functions.

•32 bits is not required for accuracy or resolution. More than 16 bits is required for addressing but bank switch may be suitable.

•Another technology direction could result in the continuation of 16 bit micros but with the addition of digital signal processing (DSP) for number crunching.

41b. What automotive application will first require a 32 bit microprocessor?

Application	Percent of respondents who listed this application
Engine/drivetrain	63%
Integrated traction/braking control	11
Navigation	9
Suspension	9

SELECTED REPRESENTATIVE OTHER APPLICATIONS

•Any application: key is fast microprocessors with a lot of memory to be able to write code in high level language and solve equations.

•Central CPU.

•Combined engine/transmission control with communications link to ABS.

•High level functional integration (i.e., the single computer control system). Artificial intelligence or expert systems for diagnostics management and/or adaptive (i.e., self-calibrating).

•Information systems.

•Communication systems.

•Distributed processing.

•Collision avoidance.

•Increase integration application, blending engine and body control, and incorporating expert system diagnostics.

•Applications with many channel calculations where precision is lost at 16 bits.

DISCUSSION

The microprocessor has found a variety of automotive applications since its introduction as the central processing unit in electronic engine control systems. In general, the performance of a microprocessor-based electronic system is influenced by the number of data bits and address bits. In particular, the accuracy of arithmetic calculations increases with increasing number of data bits.

For the past few years, the 8 bit microprocessor has been dominant in such applications as engine control where computations are performed at relatively high rates. Of course, the microprocessor cost is also proportional to the number of data bits.

In spite of increased cost, there is some justification for increasing the number of bits for engine control application alone. The present question has surveyed opinions about the future of 32 bit microprocessors. There appears to be relatively little short term enthusiasm among the panelists for 32 bit microprocessors. Rather, the trend is probably toward 16 bit microprocessor-based systems, which seem to have adequate accuracy for most automotive applications for the remainder of this century. Furthermore, most panelists expect the engine/drivetrain to be the dominant applications for 32 bit microprocessor, if it should find any automotive application at all.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers forecast 32 bit microprocessor introduction as being probable by 1995, whereas the suppliers forecast that it is unlikely.

STRATEGIC CONSIDERATIONS

The computational capability and computation speed requirements for systems requiring microprocessors continue steadily to increase over the years. The increased functional requirements and the move toward system integration are strong motivation to move to microprocessors with 16 or 32 bits. Such microprocessors will have significantly higher capacity to perform rapid calculations required for such applications as advanced engine control or suspension control. At the present time it is clear that microprocessor bit size will increase from the present 8 bits. The most likely change will be 16 bit processors. Indeed there are presently 16 bit automotive microprocessors. The 32 bit microprocessor is not expected to be widespread use until after the year 2000.

42a. What percentage of NAPPV will use electrically erasable programmable read-only-memory in automotive applications by the years indicated?

Median Response		Interquartile Range	
1995	2000	1995	2000
50%	95%	50/50%	90/100%

SELECTED EDITED COMMENTS

•I mean three types: 1) 5 volt byte alterable EEPROM; 2) 5 volt byte alterable static RAM backed up by EEPROM; 3) 5 volt block alterable EEPROM (Flash).

•Assembly plant and/or field programmable technology.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers agree to within 5%.

42b. In what applications will these EEPROMs be used?

Application	Percent of respondents who listed this application
Engine/drivetrain	84%
Calibration applications	80
Instrumentation	64
Diagnostics	56
Suspension	32

SELECTED REPRESENTATIVE APPLICATIONS

•Body computers.

•Flight recorders and restraint systems.

•Keyless entry. Remote entry.

•Reduce delay in implementing control or diagnostic changes.

•On-line display formatting and service re-calibration to avoid hardware replacement.

•Personalization.

•"Calibration" data for powertrain or any other vehicle system requiring unique "calibrators" for every vehicle; solid state odometers; flight recorders.

•Entertainment.

DISCUSSION

The EEPROM will probably to be used in essentially all vehicles by the year 2000 in one application or another. The table in 42b has rank ordered the applications forecast by our panelists for EEPROMs. Most panelists expect the EEPROM to be used for engine/drivetrain control code and/or calibration parameter storage. In addition to the tabulated results, selected representative applications are presented for single panelist's responses.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The differences between manufacturers and suppliers are so large that both round 2 median results are given:

Application	Manufacturers	Suppliers
Engine/Drivetrain	91%	44%
Calibration applications	91	71
Instrumentation	82	50
Suspension	36	29
Diagnostics	64	50

STRATEGIC CONSIDERATIONS

Programmable read only memory (PROM) is a computer memory chip which is used to store programs and/or data. It cannot be altered by the computer system once the data or program has been stored (figuratively--"burned in").

A PROM is used for such applications as engine calibration parameter storage of in an electronic engine control system. Once the data has been stored, it can only be altered by replacing the PROM with a substitute chip which has been differently programmed.

The EEPROM is a form of read only memory which is programmable and electronically erasable. However, the procedures for changing the memory content are not compatible with rapid read/write operations such as those used with RAM memory. Once the data has been entered into the EEPROM, it will remain in the memory until electrically erased.

The EEPROM has the capability to store large amounts of data in a non-volatile memory. It is partially useful for storing programs (e.g., engine control) and system parameter values (e.g., engine calibration).

The cost of EEPROMs will decrease with time as the storage capacity increases. Some panelists expect that EEPROMs will compete successfully with CD ROMs for very large storage (e.g., navigation data).

43a. In what year will Gallium Arsenide (GaAs) technology first appear in commercial automotive production (30,000+ units)?

Median Response	Interquartile Range
1998	1996/2000

Ten percent of respondents said that GaAs would never appear in commercial production.

SELECTED EDITED COMMENTS

•GaAs technology is not maturing very fast and, therefore, in the near term does not appear to be cost effective or reliable.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers forecast GaAs introduction by 1998 whereas suppliers forecast introduction by 2000.

43b. In what applications will these Gallium Arsenide (GaAs) chips be used?

GaAs Applications	Percent of respondents who listed this application
Sensors in hostile environment	44%
High-speed computer	7

SELECTED REPRESENTATIVE OTHER APPLICATIONS

•Collision avoidance.

•Engine/powertrain/chassis controls.

•Fiber optic receivers and transmitters.

•High temperature position sensors--Hall effect.

•Power switching to replace relays.

•Radar (collision avoidance).

•Satellite communications.

•True AI/expert systems, and navigation using GPS.

•Entertainment.

DISCUSSION

There are numerous technical problems limiting commercial introduction of GaAs semiconductor devices including high cost and relatively poor yield. The panelists do not expect to see applications before the end of the century. At least 10% of the respondents do not expect GaAs to ever appear in automotive applications. If GaAs integrated circuits are to appear commercially they will be introduced for hostile environment (e.g., underhood) applications.

STRATEGIC CONSIDERATION

Gallium Arsenide (GaAs) is a semiconductor material which has a number of potential advantages over conventional silicon material. It is a particularly good semi-conductor material for high temperature environments such as underhood sensors or signal processing circuit implementation. It also has potential high density packing advantages for integrated circuit fabrication. Military applications are the primary motivation for GaAs devices development. At the present time, potential military applications include high frequency circuits and solid state sensors.

44. How many microprocessors do you expect to see in the various category vehicles by the year indicated?

	Number of microprocessors Median Response		Interquartile Range	
	1995	2000	1995	2000
High Technology/Low Volume (e.g., Mark VII, Corvette, LeBaron)	10	15	8/15	10/20
Low Technology/High Volume (e.g., Escort, Sundance or Acclaim, Cavalier)	4	7	3/5	4/10

SELECTED EDITED COMMENTS

•Hard to estimate because of the integration of functions now beginning to take place.

•High end vehicles imply more "standardized" features.

•Includes microprocessor-type custom devices.

•Today there are typically 3-4 in an instrument cluster. I am including 4 bit, 8 bit, 16 bit, 32 bit, and bit slice machines.

•Active ride control.

•Crash sensing/restraint systems.

DISCUSSION

The number of functions performed by any given microprocessor-based system is limited by the computational capacity of the particular digital system. Obviously the number of microprocessors on any vehicle depends upon the number of electrically accomplished vehicle functions which, in turn, is a function of the vehicle content level. The separation of this question into high technology/low volume vs. low technology/high volume is a recognition of the influence of vehicle cost on the number of microprocessors used in the vehicle. Regardless of the type vehicle or technology, the panelist response to this question indicated the continued expansion of the application of microprocessors to automotive electronics.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Both manufacturers and suppliers forecast identical numbers of microprocessors on high tech/low volume vehicles. However, for high volume/low tech, the manufacturers forecast 1 more than the suppliers in 1995 and 2 more than the suppliers in 2000.

STRATEGIC CONSIDERATIONS

The microprocessor was first introduced in automotive electronics as a part of the evolution of electronic engine control from the earliest analog systems to the present digital computer engine controls. The ever decreasing cost/function of the microprocessor is responsible for increasing the use of this powerful device. Automotive applications for microprocessors will continue to expand because of extraordinary versatility and high cost effectiveness of the device. In addition to very sophisticated applications such as engine/drivetrain control or suspension control, microprocessors are sufficiently cost effective for such tasks as radio tuning and digital clock control.

The number of microprocessors in NAPPV is partly influenced by system integration. There is a trend to combine several vehicle functions in a single microprocessor-based digital system. The number of multi-function microprocessor-based systems obviously limits the total number of microprocessors used in any given vehicle (e.g., see question 47).

45. In what year will the following microprocessor configurations see widespread commercial production (>30,000 units)?

	Median Response	Interquartile Range	Percent of respondents who listed "never"
16 bit microprocessor	1991	1985/1994	20%
32 bit microprocessor	1995	1994/1998	20
Reduced instruction (RISC)	1997	1993/1997	9

SELECTED EDITED COMMENTS

- RISC too poorly defined to be useful. Ford EEC-I might be defined as RISC.

- Ford had 8061 in 1983. It is 16 bit.

- Widespread commercial (automotive) production assumes greater than 1 million units. 30,000 = prototypes.

DISCUSSION

The majority of our panelists (80%) seem to see a rather orderly progression from the present day 8 bit microprocessor dominated electronic systems through 16 bit, eventually reaching 32 bit microprocessor based electronics. However, 20% of our panelists forecast that neither of these microprocessor configurations will ever reach commercial production.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturer and supplier forecasts agree to within one year for 16 bit and 2 years for 32 bit.

STRATEGIC CONSIDERATIONS

The 8 bit microprocessor has become a "work horse" for various automotive applications. For example, presently the vast majority of engines control systems are implemented using 8 bit microprocessors. However, increasing complexity of engine control, including the need for improvement in transient performance and on-board diagnosis is motivating a change to greater microprocessor capacity and capability. In addition, some new functions such as integrated engine/drivetrain, suspension, and anti-lock braking control will greatly tax the capability of 8 bit microprocessor-based control systems. The 16 bit microprocessor seems destined for widespread commercial use by the early 1990's by all North American automotive manufacturers.

46. In addition to those functions which are electronically implemented in model year 1988 NAPPV, what new functions will be electronically implemented by the years indicated?

For 1995, the panelists have suggested the following new vehicle functions:

Active damping for electronic suspension, traction control; advanced navigation; personalization of settings for mirrors, radio and comfort system; voice recognition as a driver input; electronically controlled steering.

For the year 2000 the following new electronic functions have been suggested:

Variable valve timing; electronic throttle control (drive-by-wire); collision avoidance system which is coupled to drivetrain, braking and suspension; smart sensors and actuators for all electronic control systems; full diagnostics of vehicle systems via expert system; electronic vehicle maintenance records; navigation coupled to driver information via a centralized host computer for given driving area; vehicle following cruise control; rear obstacle detection; office aids in vehicle (e.g., computer, FAX).

DISCUSSION

The panelists' responses to this question suggest no significant breakthrough in function by the year 1995. Each function listed for this period is an evolutionary extension of concepts which have been experimentally tested or conceived by the year 1988. The responses for 2000 suggest new functions which integrate the vehicle with the highway system. For example communication of valuable traffic data from a localized highway supervisory system to suitably equipped vehicles as well as vehicles following cruise control systems are remarkably new functions compared to 1988 production, R&D, and demonstration vehicles.

STRATEGIC CONSIDERATIONS

A significant new attitude of the consumer was created by the utilization of advanced electronic technology on automobiles. Electronic engine control has come to be accepted by customers as a mature state-of-the-art technology. Similarly, electronic instrumentation has appeared to be routinely applied in various vehicles.

In many market segments, introduction of new electronic technology has come to be a competitive strategy. In such cases, the electronic function is clearly visible to the owner/driver, and not merely an "invisible" technology which is part of a vehicle system (e.g., electronics in engine control).

The evolution of electronic technology has enabled the introduction of new vehicle functions beyond those which appeared in the 1988 model year. This question has surveyed opinions about the new functions which might be implemented commercially by the year 2000 and has found some imaginative forecasts for this period.

47. Which electronic sub-systems are likely to be integrated into a single electronic system and which are likely to remain stand-alone sub-systems by the years indicated?

Percentage of respondents who selected each category				
	1995		2000	
	Integrated System	Stand-alone	Integrated System	Stand-alone
Engine	76%	24%	86%	14%
Transmission/drivetrain	33	67	10	90
Suspension	25	75	55	45
ABS anti-lock brakes	40	60	86	14
Acceleration skid control	55	45	10	90
Steering	10	90	33	67
Drive-by-wire	24	76	65	35
Occupant protection	15	85	26	74

SELECTED EDITED COMMENTS

- Assume "single electronic system" does not mean shared high speed or discrete data.

- Engine/transmission as one powertrain unit. ABS and traction as one unit. Year 2000 sees distributed controls linked via networks.

DISCUSSION

The responses of the panelists indicate a strong trend toward integration of on-board electronic systems. Systems such as engine and drivetrain, anti-lock braking, and skid control show strong coupling in the results of our survey. The only systems that can be expected to remain stand-alone are steering and occupant restraint.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers consistently forecast higher integration of electronic systems than the suppliers for both year 1995 and 2000. For example, the manufacturers forecast essentially 100% engine/drivetrain integration by the year 2000, as compared to only about 80% for the suppliers.

STRATEGIC CONSIDERATIONS

Traditionally, new electronic systems or functions have been added to vehicles as stand-alone systems with little or no coupling to other electronic systems or subsystems (apart from the power supply). This is a natural consequence of the way new electronic systems are developed, through engineering and pre-production prototypes developed by separate design and engineering staffs. It has been common practice to introduce new functions in production as stand-alone systems.

However, there is a strong trend in the industry to integrate certain electronic functions in combined systems, particularly where common data is shared and where overall vehicle performance can be optimized. Certain functions are naturally combined in a single system such as ABS and anti-lock functions.

The results of our survey show the increasing integration of electronics throughout the remainder of this century (and probably into the future as well). It seems that systems engineering is finally coming to the automobile industry.

48. **Which of the physical variables listed below will be sensed (on board the vehicle) using smart sensors (i.e., sensors incorporating some form of electronic signal processing) by the year 2000? Please list applications for the corresponding smart sensor.**

Percent of respondents who listed this application		
	Smart Sensors	
Physical Variable	Yes	No
Acceleration	81%	19%
Velocity	58	42
Displacement/position	81	19
Pressure/force	81	19
Fluid flow	54	46
Gas chemistry	62	38
Fluid level	60	40
Temperature	54	46
Please see Table on next page for Applications.		

SELECTED EDITED COMMENTS

•Cost penalty between smart and conventional sensors will be the primary factor influencing rate of use.

•Smart sensors will be widely available at extra cost over conventional sensors.

DISCUSSION

In the so-called smart sensor the sensor element is fabricated on a silicon substrate which permits incorporation of some electronic signal processing on the same silicon wafer as the sensor element. This signal processing can automatically compensate for defects in the basic sensor such as temperature dependent calibration. It is clear that the panelists expect to see significant development of smart sensors by the year 2000 for: measurement of acceleration to be used in traction or braking control; displacement for electronic suspension systems; pressure sensors for in-cylinder pressure measurement with engine control applications.

The trend toward smart sensors for monitoring other variables is less clear. However, the use of a smart sensor for exhaust gas chemistry measurement is a likely new development. This smart sensor must operate at extremely high temperatures compared to the normal solid state environment. This is a potential early application for a GaAs semiconductor smart sensor.

Variable	Application	Percent of respondents who listed this application
Acceleration	Traction or braking control	33%
	Suspension	22
	Transmission control	16
	Air bag	16
Velocity	Traction or braking control	29%
	Vehicle speed (instrumentation)	21
	Suspension	14
	Engine control	13
	Navigation	7
Displacement/ position	Suspension	33%
	Steering	20
	Throttle position	13
	Miscellaneous	10
Pressure/force	Cylinder pressure for engine control	61%
	Suspension	17
	Transmission control	11
	Manifold pressure	5
Fluid flow	Mass air flow for engine control	50%
	Fuel flow for fuel economy	40
	Coolant	10
Gas chemistry (including EGO)	Exhaust emissions/CAFE	67%
	Flexible fuel systems	13
	Air quality sensor	13
	Analysis of exhaust gas	6
Fluid level	Fuel quantity	40%
	Oil quantity	40
	Coolant quantity	20
	Brake fluid	10
Temperature	Engine	57%
	Air conditioning	28
	Oil	14

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers agree to within 5% for all sensors except fluid level and temperature. For these sensors the manufacturer forecasts are about 25% higher than the supplier forecasts.

STRATEGIC CONSIDERATIONS

Smart sensors are an outgrowth of solid state sensor technology and have the potential to provide substantial system improvements over conventional sensors. A smart sensor can provide signal conditioning which can generate output data in a digital format, this being maximally useful for any digital system. For example, a smart sensor can provide a direct on "chip" analog to digital conversion such that the digital system can receive data in a digital format, eliminating the need for a system analog to a digital convertor.

In addition, a smart sensor can transfer data at a minimal data rate to the digital system, thereby placing a minimal burden on the system's computational capability. It can also compensate for calibration changes (e.g., due to temperature effects) and can correct for nonlinearities in sensor elements. Optimally configured smart sensors have the capability of reducing total system cost and complexity, and will offer several interesting market opportunities. With potential advantages, it can be expected that smart sensor development will continue.

49. Will redundant microprocessors be required by legislation for critical safety-related functions such as anti-lock braking or passive restraint systems?

No: 76%	Yes: 24%

SELECTED EDITED COMMENTS

•Fail-safe is more important and solutions can be found without redundant microprocessors.

•By practice maybe. Not legislation!

•I do not see a move in that direction. However, safety systems such as ABS or traction control will be required by law by 2000.

•Mean time between failures will improve for all electronics.

•Not before 2000.

•Redundant and fail-soft will be a design decision but multiple microprocessors may not be the best solution.

•Redundancy does not insure safety. Multiple redundancy will be too expensive and, probably, not reliable. Software safety will be the critical issue.

•The government will avoid the "how's," but will specify the "what's."

•Until redundant system back-up is possible.

•Yes, unfortunately.

•No, the EPA has learned to write performance requirements. Presumably means provable fail-soft (but not how you do it).

DISCUSSION

The use of hardware redundancy has long been a tradition in the aerospace industry where reliability is often a critical safety-related issue. In automotive applications such as electronic engine control, reliability is less of a critical safety related issue than one of customer satisfaction. A failure in engine control is inconvenient but owing to backup "fail-soft" operating mode, is not necessarily safety related. Furthermore, hardware redundancy is very costly in the competitive automotive environment. A majority of our panelists (76%) do not expect to see microprocessor redundancy mandated by legislation or regulation.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The responses of the two groups differ by less than 5%.

STRATEGIC CONSIDERATIONS

Hardware redundancy means identical copies of a given system are provided so that multiple simultaneous failures of given system are highly improbable. Typically, three or more redundant systems are provided. If a system should fail then its output will differ from that of the other two (or more) systems being simultaneously monitored. The odd system is declared "failed" and one of the other systems is then used as the primary system.

This method is not normally used for most automotive systems, because the cost of hardware redundancy is excessive. Alternatives to hardware redundancy include fault/failure tolerant systems or fault analysis through analytic redundancy. Such systems have the potential to provide some of the safety benefits of hardware redundancy without the cost penalty.

50. Will it be required by legislation/regulation that software be certified for safety-related microprocessor-based subsystems?

No:	77%	Yes:	23%

SELECTED EDITED COMMENTS

•It would be very difficult to verify "bug-free" software. It would make more sense to certify an entire system, e.g., engine emission levels, etc.

•Liability issues will force at least some standards, if not certification.

•Not before 2000. Redundant microprocessors and certified software still do not insure "safety." Perhaps a "certified design" by some agency like FDA would ease liability concerns.

•Or required by documentation on file.

•This is a distinct possibility. The question is "certified" to be what?

•Yes, only if other safety-related electronics are legislated.

•Nobody knows what certified means. Exhaustive testing may be impossible. Some proof of due care may be required.

DISCUSSION

The majority of our panelists do not expect to see certification of computer programs for safety-related microprocessor-based automotive electronic systems (e.g., ABS). At the present time it is not clear what form the certification might take, although some demonstration of fail-safe system operation could be required and would be considered by some to be a form of certification.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Only about 18% of the manufacturers expect legislation/regulation to require certification of safety related subsystems compared with about 27% of the suppliers.

STRATEGIC CONSIDERATIONS

Certification of software is a process of demonstrating to the appropriate government agency that a system meets mandated safety standards. Identification of possible failure modes occurs through analysis of a given system operation under control of the software. Typically, this certification process might include simulation of possible failures and demonstration that the system can tolerate failures without catastrophic results.

51. Do you foresee that each microprocessor-based electronic subsystem will be required by legislation/regulation to have self-diagnosis capability?

No:	77%	Yes:	23%

SELECTED EDITED COMMENTS

• Self-diagnostics is only a means to an end, i.e., better serviceability.

• Already starting in California.

• Cost, reliability, and maintainability will force this capability.

• California may legislate for engine applications.

• I believe a base line (lower functional level) will be required on all microprocessor unit control systems that relate to emission control.

• No, if not a safety issue.

• Not often the best alternative.

• Yes, if emission related or safety critical.

• Response to Questions 49, 50, 51 all together: if one goes they will all go.

• There is too wide a spectrum of applications. In a convenience function like radio or seat positioning the only reason to have diagnosis is to reduce repair cost.

• Vehicle manufacturers will drive this requirement and have already begun to.

DISCUSSION

As in the previous question, a majority of panelists do not expect to see regulation/legislation requiring self-diagnosis for any microprocessor-based electronic system or subsystem. It seems from the comments that self-diagnosis will be a part of the system design and that regulation/legislation will not be required.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

About 32% of the manufacturers expect requirements for self-diagnosis through legislation/regulation as compared with only about 12% of the suppliers.

STRATEGIC CONSIDERATIONS

Some form of self-diagnosis is common on any microprocessor based system. The critical technical issue relating to self-diagnosis is the total burden on the computation capability of the system. Self-diagnosis is a form of "overhead burden" which is normally expected in such systems.

There is great incentive to maximize the efficiency of self-diagnosis algorithms to assist in lowering diagnosis "overhead." On the other hand, there are benefits to self-diagnosis which may bring it into being on all microprocessor-based electronic systems without governmental intervention. For example self-diagnosis can greatly reduce the diagnosis problem faced by a repair technician relative to his unaided efforts.

To some extent, the implementation and level of sophistication of self-diagnosis is influenced by the computational efficiency of the related algorithms. As this efficiency is improved, there will be a greater utilization of self-diagnosis on all microprocessor-based systems, regardless of governmental regulation or legislation.

52. What percentage of electronic systems or subsystems in NAPPV will use Tape Automated Bonding (TAB) by the years indicated?

Median Response		Interquartile Range	
1995	2000	1995	2000
10%	25%	5/20%	20/50%

SELECTED EDITED COMMENTS

•TAB technology could be replaced by a breakthrough which allows higher density packages and improved automation.

DISCUSSION

Tape automated bonding is one assembly method which can be used for electronic assembly. Our panelists predict a modest growth in the use of TAB for the remainder of the century.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers agree to within 5% for 1995 and give identical results for the year 2000.

STRATEGIC CONSIDERATIONS

Electronic fabrication/assembly involves a non-trivial portion of the cost of automobile electronic systems. Automated assembly is an absolute requirement in the highly competitive automotive electronic environment.

53. What percentage of automotive electronic systems will be fabricated using the indicated technology in the following years?

Technologies	Median Response 1995	Median Response 2000	Interquartile Range 1995	Interquartile Range 2000
Polymer thick film	10%	10%	5/10%	5/15%
Molded Printed Wire (PWB) board	5	10	2/10	1/20
Chip and wire on PWB	5	5	2/15	0/15
Surface mounting	70	80	40/80	50/100
Ceramic thick film	10	10	5/30	5/20

OTHER RESPONSES INCLUDED

Molded plastic hybrid (multi chip package): 1995=5%, 2000=15%.

Polyimide flex-rigid PWB: 1995=10%, 2000=20%.

Conventional Printed Circuit (PC) board: 1995=60%, 2000=20%.

Conventional and new-unspecified (2000): 1995=42%, 2000=35%.

SELECTED EDITED COMMENTS

•The above technologies are emerging into potential high volume automotive use.

•Choice of technology will be made independent of the technologies themselves, therefore no accurate estimates can be made.

•Significant factors must "occur" for the industry to move away from FR4PWB.

DISCUSSION

Of all the assembly technologies specified above, surface mounting has the greatest long term potential. This technology is finding increased use throughout consumer electronic assembly. Our panelists forecast that surface mounting will become the dominant technology by the year 1995 and will be almost exclusively used by the year 2000.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Both manufacturers and suppliers agreed to within 5%.

STRATEGIC CONSIDERATIONS

For many years the standard electronic assembly methods involved mounting dual in-line package (DIP), in-line-pin integrated circuits "chips", and other components on printed circuit boards.

Automated equipment installed all components on a predrilled and plated printed circuit board. Automated soldering is used (e.g., wave soldering equipment) for final electrical assembly.

The trend in electronic assembly is to use integrated circuits which are packaged in such a way to allow easy attachment on the printed surface circuit board. This surface mounting technology is very mature and has cost advantages over the conventional method. For these reasons surface mounting will be almost exclusively used in automotive electronic assembly.

54a. Do you foresee that vehicle electrical system voltages will increase from 12 volts in the years indicated?

	1995	2000
Yes	19%	78%
No	81	22

SELECTED EDITED COMMENTS

•Either 100% higher voltage (i.e., 48 volts) or dual voltage (12 and 48 volts).

•Except combination 12/24 volt system.

•Except within high power subsystems such as heated windshields.

•Picture for 1995 is unclear. Some speciality may have 24 or 48 volt systems by 1995.

•Possible dual supply by 2000, with 12 volts retained for lighting.

54b. If yes, what voltage level and what maximum current do you expect?

	Median Response		Interquartile Range	
	1995	2000	1995	2000
Voltage level	12	48	12/24	24/48
Maximum current (amp)	100	100	70/125	50/100

SELECTED EDITED COMMENTS

•Voltage level in 2000=24, up to 48 volts. Maximum current in 2000=150 amps.

•48 volt will be in addition to existing 12 volt, 140 amps supply by 2000.

DISCUSSION

There seems to be relatively little question that the voltage level of automotive electrical systems will increase. The only uncertainties are the voltage level and the model year in which the voltage will change. The majority of panelists believe that the change will occur between 1995 and 2000. From the responses for question 54b about 60% of the panelists believe that the voltage level will remain at 12 volts (with current capacity at or below 100 AMPS) through 1995. Again, 75% of the panelists expect to see 48 volt power supply by 2000.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Both manufacturers and suppliers agree that the most probable time for voltage change will be between 1995 and 2000. However, the manufacturers forecast a change to 48 volts whereas the suppliers forecast a change to 24 volts. Both groups forecast 100 amp current capacity.

STRATEGIC CONSIDERATIONS

There are several issues involved in changing voltage levels. A slight reduction in vehicle weight and an increase in power supply efficiency can be achieved by raising power supply voltages through using smaller diameter wires in the harness. However, the storage battery must have more cells than in the present 12 volt system. On the other hand, virtually all on-board electrical systems are affected by this change. All interior and exterior lighting must be changed to operate at the higher voltages. All motors and solenoids must similarly be redesigned. Electronic systems can (in principle) be operated at higher voltages than the present 12 volts by simply changing the voltage regulator circuitry. Clearly a change in voltage will require some modification to virtually all electrical/electronic systems. Such a change does not come without cost. Nevertheless, the majority of panelists expect to see a change to higher voltages by 2000 possibly also maintaining a 12 volt system as well.

55. Do you foresee that dual voltage or multiple power buses (including an AC bus) will be provided? If yes, please give the year of introduction.

		Median Response Year	Interquartile Range Year
Yes:	81%	1997	1995/1998
No:	19%		

SELECTED EDITED COMMENTS

- On select vehicles.

- Used since 1986. AC used in 1989 as power transmission method to heated front glass. The best voltages and modes will be provided for the tasks at hand. This will also allow improved battery storage methodologies.

- Ford has unregulated high voltage AC today for heated windows. In certain other applications it will arise near term.

DISCUSSION

A majority of the panelists expect dual voltage multiple power buses on NAPPV to appear somewhere in the interval between 1995 and 2000. This is in addition to the present use of unregulated AC power for front windshield defrosting (which is an ad hoc use of generator power as opposed to a true secondary power bus). Dual voltage power supplies have the potential benefit of avoiding a complete redesign of all vehicle electrical systems. For example, the present 12 volt bus and power supply could be retained for lighting purposes, but a higher voltage bus could be provided for other electrical system needs. However, the change to higher voltage or dual voltage electrical systems will involve significant engineering and manufacturing changes.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

A much higher fraction of the manufacturers (94%)suppliers than suppliers (67%) expect to see dual electrical power buses. The manufacturers forecast this to occur by 1996, whereas the suppliers forecast it to occur by 1998.

STRATEGIC CONSIDERATIONS

Modern automotive electrical systems receive power from an engine driven alternator. The alternator produces alternating voltage at its terminals. The DC power required to charge the battery is obtained using a diode circuit along with an electronic regulator circuit. This circuit combination delivers power to the battery, maintaining the desired charging level.

The automotive alternator is capable of delivering electrical power to support separate electrical bus systems. For example, unregulated alternating current is available from the alternator terminals. Moreover, separate electronic circuits can provide DC power to more than one electrical power bus.

Thus, if desired, dual (or multiple) power supply buses can readily be provided from a single alternator.

56. Which of the following battery techniques are likely to be incorporated for applications such as memory protection of on-board clocks?

	Percent of respondents who listed this application	
Application	1995	2000
Lithium	32%	48%
Alkaline	24	8
Other	0	4

SELECTED EDITED COMMENTS

•Rechargeable, Ni/Cd or Ni/Fe.

•It is difficult to perceive a need for these techniques.

•Lithium batteries may be used in some niche automotive applications but use in clocks is doubtful because of cost vs. benefit.

•Use of batteries (other than main battery) will phase out completely with use of EEPROM. True built information will come from data built time/data stamp and hours running counter. Preservation of "on-board-clock" has no value and customer value is negligible.

•Will be avoided due to serviceability consideration.

DISCUSSION

Neither of the identified battery technologies seem to have much likelihood of adoption for memory protection by the year 1995. However, the lithium battery has a relatively high probability (64%) of being used by the year 2000.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Manufacturers and suppliers agree to within about 10%.

STRATEGIC CONSIDERATIONS

The microprocessor has come to be used in virtually every electronic subsystem from clocks and radios to engine/transmission control. Each such system has memory which ideally should store data or keep functioning (as in the case of a clock) when the vehicle is switched off. Small stand alone batteries have been proposed to maintain data in read/write memory. This question has surveyed opinions on the use of the most prominently mentioned battery technology.

VI. COMFORT/CONVENIENCE/ENTERTAINMENT

57a. Do you foresee significant improvement in on-board diagnostic capability for electronic engine control systems? If yes, indicate year introduced and the improvement expected.

		Median Response Year	Interquartile Range Year
Yes:	77%	1993	1992/1995
No:	23%		

Improvements:

- Circuit level diagnostics.
- Misfires, system electrical shorts, etc.
- Better fault isolation.
- External mainframe hookup. "Flight recorder" memory for intermittent fault detection.
- Identification of lowest replaceable unit (LRU).

- Much better identification of transient problems.
- Multiplex database.
- Pinpoint control element failure with implementation of fully distributed high speed networks and smart sensors and actuators.

- Self diagnosis--owner fixing problem.
- Significant for truck products.
- Standard diagnostic connector, test modes, and serial data protocol.
- Trouble shooting records.

SELECTED EDITED COMMENTS

- Better reliability and fail safe approaches.

- Diagnostics of software as well as hardware.

- Full active system diagnostics.

- More than likely a continued expansion of on-board/off-board diagnostic improvements (not one significant year or event) in which the goal is to "fix-it-right" the first time in for service.

- Readout not on-board.

- Significant on-board diagnostics already available and will expand.

- Too expensive--requires smart sensors.

- Cartridge hand held testers. Off-board systems.

•Even for non-intermittent it may be best to process part of the information on-board.

DISCUSSION

The vast majority of panelists expect to see significant improvement in on-board diagnostic capability by the year 1995. However, there does not appear to be any clear consensus on what actual improvement will be. It appears that panelists expect better isolation of faults and more precise identification of specific failures.

Curiously, no panelist mentioned the proposed changes in California for on-board diagnostics which have generally been called OBD II. These changes in on-board diagnostic capability are potentially far-reaching and (apparently from the responses of the automotive OEMs to the proposed changes) are relatively significant diagnostic changes. There does appear to be agreement among panelists that there will be improvements in access of the service bay diagnostic equipment to on-board data. Such improvements will occur along with on-board diagnostics capability improvements.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

There are virtually identical forecasts by the two groups on whether significant on-board diagnostic capability improvements will occur. The manufacturers forecast a 1993 introduction; suppliers see a 1997 introduction.

STRATEGIC CONSIDERATIONS

On-board diagnosis of problems related to any given electronic system are critical to system reliability. Typically tests are performed during a portion of the operating cycle of any microprocessor-based control systems. Such self-diagnosis can rapidly detect abnormal behavior in critical components (e.g., sensors or actuators). Indication that a failure has occurred is via a special "fault" code stored in a particular memory location and via an instrument panel indicator lamp.

57b. If diagnostic system improvements are brought about will it then be possible to diagnose relatively short-term intermittent faults? If so, when?

		Median Response Year	Interquartile Range Year
Yes:	91%	1995	1992/1996
No:	9%		

SELECTED EDITED COMMENTS

•Again, emphasis will be on better reliability.

•I think this will happen prior to above through networks (lower speed) and memory storage like EEPROM for fault codes and/or fault history.

•It will vary by car manufacturer and philosophy of how to diagnose a vehicle. Some of this functionality is already showing up on vehicles now. The problem is defining "fault" and "short-term."

•Types of faults remembered will expand.

DISCUSSION

The majority of panelists expect diagnostic system improvements to enable diagnosis of relatively short-term intermittent faults in electronic systems. The relatively large spread in the interquartile range may reflect uncertainty in the exact meaning of short-term intermittent faults. For our purpose we define these as faults which persist for less than one minute. Regardless of any uncertainty in the exact meaning of "short-term," our panelists are in nearly unanimous agreement that such faults will be detectable/diagnosable.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

About 95% of the manufacturers expect that the capability to diagnose short-term intermittent faults will exist by 1995. However, about 87% of the suppliers expect this development to occur by 1993.

STRATEGIC CONSIDERATIONS

It is well recognized that intermittent faults in any component of a system are difficult for the mechanic to diagnose. On-board digital systems can detect such faults and store codes in memory to alert the mechanics. Ultimately such a procedure has great potential for improving vehicle reliability and customer satisfaction.

Rapid and efficient diagnosis of automotive systems plays a key role in improving maintenance of automobiles, and thereby improving customer satisfaction. Diagnosis is performed both in the service bay and on-board the vehicle. For example, the electronic engine control system has a substantial self-diagnosis capability. The engine control system monitors performance of all sensors and switches. Open-circuit or short-circuit tests are conducted for each sensor and actuator. In addition, values for significant variables and parameters are examined within gross limits. Whenever failures or errors are detected in any component, a special code is set corresponding to the failed component.

In the service bay, the mechanic can examine the failure codes which are stored in the control unit memory. If necessary, service bay equipment having somewhat more capability than the on-board system can be brought to bear on any given problem. The on-board diagnostic system can maintain fault data (logged appropriately) intermittent or short-term faults which can later be examined by the service bay equipment. In this way, it may be possible to identify the type of intermittent faults which are so troublesome to customers.

57c. When do you expect to see widespread use of artificial intelligence (AI) techniques for diagnosis of automotive maintenance problems in the following diagnostic systems?

Diagnostic System	Median Response	Interquartile Range	Never
Service bay	1994	1991/1995	2.6%
On board	1997	1995/2000	21%

SELECTED EDITED COMMENTS

•"CAMS" is a form of AI.

•AI unlikely to replace the well-trained mechanic but will have its place for hard to solve problems.

•I think that the cost sensitive market will preclude AI from being on-board unless the cost issue goes away based on new technology.

•Limited service bay application by 1992.

•On-board systems would be expensive to maintain in the sense that update of the AI system (database, rules, etc.) would be costly but necessary as field problems are discovered in future years.

•Should not be required where factual diagnostics can be made.

•Not black and white--it will be easier to use monitoring equipment on-board to capture special data.

•Possible now. Requires EEPROM, a diagnostic port on the engine computer and memory space.

DISCUSSION

The median year forecast for service bay application of AI (expert system) suggests that this application has gone beyond the experimental stage. From the various comments made by the panelists, it seems clear that some form of AI will be in the service bay by about 1994-1995.

As at least one panelist has indicated AI is currently available in such systems as the GM CAMS. However, the present day system probably would not be viewed strictly as an expert system by most AI researchers.

It is not surprising that few panelists ever expect to see any significant form of AI on-board the vehicle. The relatively large memory required for rule-based diagnosis (e.g., expert system) precludes on-board AI for the foreseeable future. However, service bay systems are likely to incorporate (at least limited) AI before 1995.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Manufacturers expect AI in service bay applications by 1994 and suppliers expect this by 1995. If on-board AI diagnostic applications are developed, availability is forecast to be in the year 1998 to 2000 by both groups.

STRATEGIC CONSIDERATIONS

There is presently considerable development of diagnosis applications of AI, particularly in aerospace applications where system complexity is large and where cost constraints are less important than in automotive applications. It is likely that automotive applications of AI will begin to appear before 2000 in the form of mechanic aid expert systems. A well-designed expert system has great potential for assisting the mechanic in solving difficult diagnostic problems. To be most useful, the expert system should be updated relatively frequently based upon information available at a host computer (e.g., at the OEM) from field repair experience.

58. Assuming the on-board diagnostics proposed by the California Air Resources Board as of October 31, 1988 were to become law, will new technology be required to implement the proposed regulations with respect to:

	1995		2000	
New Technology Required	Yes	No	Yes	No
Misfire detection	75%	25%	50%	50%
Catalytic convertor efficiency monitoring	75	25	43	57
Canister purge system monitor	67	33	23	77
Air injection flow rate monitoring	47	53	29	71
Oxygen sensor monitoring	33	67	29	71
EGR flow rate monitoring	27	73	14	86

SELECTED EDITED COMMENTS

- All can be done today, but at what cost?
- New might come on, even if not "required." Also depends on definition of "new."
- To achieve the proposed legislation, new invention has to occur prior to 1995 to make it production ready. Since the powertrain will evolve, these will have to be re-invented to change with powertrain.

DISCUSSION

The majority of panelists agree that new technology is required for misfire detection, catalytic convertor efficiency monitoring, and canister purge system monitoring for 1995, however, most panelists seem to feel that the new technologies will have been developed by the year 2000.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The manufacturers and suppliers agree to within about 8%, except for catalytic convertor efficiency monitoring, for which 100% of manufacturers said that new technology is required by 1995 compared with 56% of suppliers; and for EGR flow rate, essentially 100% of manufacturers believe new technology is required, compared to 25% of suppliers.

STRATEGIC CONSIDERATIONS

The California Air Resources Board (CARB) has proposed a number of new regulations for diagnostics or emission systems monitoring which are to be implemented in real time on each passenger vehicle. For example, it is proposed that a misfire monitoring system be implemented.

Sufficiently high misfire rate can cause catalytic convertor temperature to rise to a potentially destructive level. The on-board diagnostic system should detect this condition and alert the driver.

In addition, it is proposed that the conversion efficiency of the catalytic convertor be monitored periodically on-board each passenger vehicle. Whenever the efficiency falls below an acceptable level, the driver is to be warned.

Additional functions to be monitored include: the evaporative emission canister purge system, secondary air injection to catalytic convertor, the exhaust gas oxygen (EGO) sensor performance, the exhaust gas recirculation (EGR) system, and the air conditioning system (for leaks).

Although proposed methods for accomplishing each task are also reported in the document issued by CARB, there is some disagreement between CARB and some automobile manufacturers of the proposed methods of compliance feasibility. This question attempts to survey opinions as to which monitoring systems requires new technology.

59. What future developments do you foresee in passenger vehicle entertainment systems in the interval from 1995 to 2000?

Development	Percent of respondents who listed this development
TV for passengers	46%
CD or DAT (entertainment)	33
Improved speaker performance	21
Multi-channel sound/individual headphones	17
VCR (for rear seat video)	12
Increased integration of entertainment systems	12

DISCUSSION

The table above presents responses in rank order for the reader's convenience. It was somewhat surprising to see more panelists suggested passenger TV than either CD or DAT. We had expected to see much more interest and enthusiasm for CD (both for entertainment and for navigational aids) than for any on-board TV. Also surprising is the lack of comments on issues like reception and quality of TV on-board a moving vehicle. Perhaps these same panelists expect to see video used with on-board VCRs. Other countries seem to have surpassed the U.S. in automotive TV In Japan, for example, automotive TV is not uncommon for passengers.

STRATEGIC CONSIDERATIONS

Passenger entertainment systems have evolved in a way which parallels developments in home entertainment systems. For example, as FM stereo broadcasting increased, so too did the demand for automotive stereo FM receivers. In addition, casette recording has found very high use in automotive entertainment, just as it has in home stereo systems. Furthermore, there has been a great expansion in accessory systems for TV (e.g., VCR, video games, computer terminals), each of which is potentially applicable in automotive entertainment systems.

With the growth in home CD systems it was natural to expect growth in automotive CD system usage. At the present time, CD has achieved a relatively high usage compared with vinyl records. The CD player can readily be adapted for automotive use and will undoubtedly increase in automotive market penetration. Probably any new home entertainment device can be expected to appear at some point, at some level, in automobiles. Furthermore, integration based upon systems engineering of automotive entertainment systems can be expected.

60. What future developments do you foresee in comfort-convenience systems in passenger vehicles in the interval from 1995 to 2000?

Comfort/Convenience Development	Percent of respondents who listed this development
Zoned climate control	49%
Personalized setting of seats/mirrors	17
On-board hot water/cooler	12
Improved air conditioning efficiency	12

SELECTED REPRESENTATIVE INDIVIDUAL RESPONSES

•By that time the "cellular " network will be used to track traffic patterns and information will be available to all on broadcast radio (local).

•CD and cellular telephones as standard equipment in all cars.

•Extended use of "memory" technology to many systems.

•Human factored instruments.

•Quieter air flow.

•Route prediction navigation.

•Smart card keyless entry.

•Keyless ignition, personalized entry, and rear visibility.

•Remote start and security signal.

•Navigation, head-up-displays, and obstacle detection.

•Integrated voice activated sensors.

•System fault recording, electronic air conditioning, and maintenance monitors.

•Refrigeration, food storage. Noise cancellation techniques.

•Electronic shutter-glass.

•Thermostatic control, energy conservation systems for AC, insulation/sun shielding.

DISCUSSION

It is clear from the panelists' responses that zoned climate control is likely to achieve widespread usage. The remaining developments cover a wide variety of potential passenger comfort or convenience items. No clear trend or set of developments can be anticipated from the features other than zoned climate control. For example, expanded use of cellular phones for such applications as data transmission and for receiving FAX messages in the car are indicated but do not receive significant responses from panelists. Various methods of keyless entry such as the "smart card," in which electronic circuits are packaged into a thin card (e.g., credit card), are suggested. This latter technology exists already (e.g., telephone dialing cards in France) and can, in principle, be adapted to automotive use.

STRATEGIC CONSIDERATIONS

As in the previous question, suggestions for new comfort and convenience systems come, in part, from related developments in home electronics. For example, zoned climate control has been available in commercial buildings for some time. Also, electronic keyless entry is routinely used to provide security in many commercial buildings and is adaptable to automotive applications. Similarly, the use of voice recognition as a means of system input is known. Voice recognition has been used to identify persons for entry into some secure military installations.

It is likely that the inspiration for future automotive comfort/convenience systems will continue to come partly from home systems. However, customer perceived value will most likely play a significant role in market success of any such system. Customers are able to judge the value added of such systems, perhaps more than in any other area of automotive systems.

61a. What percentage of NAPPV will incorporate windshield defrosting and ice removal by electric heating by the years indicated?

	Median Response	Interquartile Range
1995	10%	5/25%
2000	20	15/50

SELECTED EDITED COMMENTS

•Will not sell in Southern states.

61b. What percent of cars having electric windshield defrosting will incorporate the following technologies?

	Median Response 1995	2000	Interquartile Range 1995	2000
Thin film conducting sheet	90%	100%	70/100%	90/100%
Embedded wires	0	0	0/20	0/5

DISCUSSION

The responses of the panelists indicate a relatively low penetration of windshield defrosting. Clearly the penetration of such a feature is limited geographically to areas where windshield frosting is relatively commonplace. However, this geographic area includes more than 50% of the total market place for automobiles. On the other hand, the market penetration of this vehicle option also is influenced by the cost relative to total vehicle cost. It can be expected to be more acceptable for relatively expensive models than for the lower-end vehicles.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

Manufacturers and suppliers are within 3% for market penetration forecast. Furthermore, both agree that this windshield defrosting will be by thin film conducting sheets.

STRATEGIC CONSIDERATIONS

Virtually the only practical method panelists forecast for implementing windshield defrosting (question 61b) is via thin film conducting sheets. The use of rear-window-like embedded conductors is unacceptable from a safety standpoint as well as from the standpoint of being a nuisance to the driver.

62a. What percentage of NAPPV will incorporate a moisture-activated automatic windshield wiper system in the years indicated?

	Median Response	Interquartile Range
1995	1%	0/5%
2000	5	3/5

SELECTED EDITED COMMENTS

•Technology is feasible today. It does not appear that it would be widely accepted by the marketplace as a value-added feature.

•A true luxury.

•Cost/benefit not there.

•Diverse customer expectations will confound acceptance.

62b. In what year will a cost effective moisture sensor be commercially (30,000+ units) available?

	Median Response	Interquartile Range
Year:	1994	1992/1997

SELECTED EDITED COMMENTS

•Sensors are available today. The issue is not cost but rather reliable performance under all environmental conditions.

•Not cost effective.

DISCUSSION

The panelists have a very low enthusiasm for this feature. Most who responded believe that the customer perceived benefit will not justify the cost of the option. The cost of the sensor for automatic moisture activated windshield wipers is less inhibiting than the reliability.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

The forecast market penetration for automatic windshield wiper activation is very small for both manufacturers and suppliers, although the manufacturer forecast, are about 5% higher than the supplier forecasts.

STRATEGIC CONSIDERATIONS

A moisture activated windshield wiper could automatically optimize intermittent windshield wiper operation. At the present time, the driver manually adjusts the period of a periodically activated wiper system. As the weather conditions change, a moisture activated wiper system could modify the operation. In this way, unnecessary wiper operation which shorten wiper life could be avoided. The relative benefits for automatic wiper operation are questionable. Probably relatively few motorists would find this system worthwhile.

63. In response to mounting concerns regarding diagnostic and product liability and issues such as unintended acceleration, do you foresee the implementation of aircraft-like data recorders to record driving and operational engineering data? If yes, in what year do you foresee its commercial introduction?

		Median Response Year	Interquartile Range Year
Yes:	32%	1997	1995/1998
No:	68%		

SELECTED EDITED COMMENTS

•Not as stand-alone black boxes. However, we will continue to make on-board diagnostics more sophisticated, i.e., engine control modules will become more sophisticated to detect and store in memory (RAM or EEPROM) intermittent failures or other "unique" events.

•Data compression will have to be very sophisticated to make this concept cost feasible.

•It is more likely that this will be used to prevent warranty fraud.

•Limited capability by 1995.

•May be required first in commercial vehicles such as large trucks. Will eventually spread to consumer vehicles.

•May occur if only vehicle-related information is recorded but might not if driver behavior is recorded as this could be viewed as an invasion of privacy.

•Only for engineering development.

•Present in airbag modules now.

•They will probably not successfully be used for litigation by an auto company to prove the owner screwed up.

•When high speed distributed networking is available.

•The extremely large number of measurements required will preclude the use of such a system until essentially all systems are electronically controlled.

•Will be initially much simpler than aircraft devices and not crash-proof. May be forced into aircraft-like records if records indicate electronics are a significant factor in accidents.

DISCUSSION

The panelists are almost exactly evenly divided on this question which reflects the close relationship between potential benefits vs. cost and disadvantages. In principle such a recorder could aid in accident reconstruction and identification of potential vehicle defects relative to driver error.

Some of the technical problems identified by panelists include the relatively large volume of data which would need to be recorded and the requirement for a high speed data link from each system to the recorder, both of which are relatively costly.

COMPARISON OF VEHICLE MANUFACTURER AND SUPPLIER PANELISTS

About 36% of the manufacturers said yes, compared to 77% of suppliers. Both groups agreed that if recorders are introduced the year will be 1997.

STRATEGIC CONSIDERATIONS

Data recorders are used on transport category aircraft to aid investigators in post accident studies. Vital aircraft parameters are recorded in an instrument which is designed to survive crashes that destroy the aircraft.

There are some similar potential benefits in recording automotive data for post-crash investigation. For example, it is conceivable that the cause of many accidents can be determined from such data. In many cases it should be possible to distinguish driver error from vehicle failure as an accident cause.

There are several issues affecting the feasibility of such a system in automotive applications. Clearly such a recorder must be less expensive than the aircraft counterpart in order to have automotive application. In addition, data communication from various modules to the recorder must have adequate capacity for real time recording. Furthermore, there are questions about invasion of privacy which would have to be addressed before such a system could be installed in any vehicle.

INDEX OF QUESTIONS LISTED BY TOPICS