AUTOMOTIVE PRODUCT DESIGN AND DEVELOPMENT DELPHI

Forecast and Analysis of the North American Auto Industry Trends through 2007

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The Delphi team would also like to acknowledge the efforts of our panelists who spent untold thoughtful, reflective, and—we are sure—sometimes frustrating hours completing our detailed questionnaires.

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FOREWORD

Automotive Product-design-and-development through 2007 - A Delphi Forecast and Analysis of North American Auto Industry Trends

Background

This study focuses on North American auto industry philosophies, practices, and tools for various phases of the product- development process, and their impact on cost, quality, and design lead time.

The Delphi forecasting process is a systematic, iterative method of forecasting based upon the judgement of a panel composed of knowledgeable experts. Panelists respond to an initial round of questions, and, depending on the level of consensus, a second "round" of questioning may be conducted. Respondents provide their second-round responses after receiving a statistical summary of first round responses. This process helps in identifying consensus on opinion-based questions. OSAT has been performing such forecast studies of technological developments in the automotive industry since the inception of the office in 1978.

Purpose of the Study

The rapid pace of advancement in design technologies and information-transfer technologies has changed the nature of competition in the automobile industry worldwide. Product and process innovations have resulted in a market where new-product-development time has to be cut dramatically if companies are to remain competitive. Customers demand that manufacturers deliver products at affordable prices with a wide array of attributes. In this environment, automakers who can successfully streamline their product-development and manufacturing operations to trim excess cost and introduce innovative products will be the most likely to capture market share.

The study provides the industry a snapshot of current expectations for the Product Development process, including the use of computers and communication media, design technology and systems, and technical and managerial skills. This should assist readers in developing a better understanding of the many factors at work in the product-design process.

Ernst & Young, LLP, and the State of Michigan Jobs Commission funded this work. The project team worked closely with representatives of these organizations in the development, analysis, and write-up of the project. The authors of the report are University of Michigan faculty member Sridhar Kota (UM College of Engineering) and Gerald F. Londal (GM, retired), and Michael S. Flynn (Associate Director of OSAT).

Panel Characteristics and Composition

The very essence of a Delphi survey is the careful selection of expert respondents. The selection of such experts for this Delphi survey is made possible by the long-standing association between The University of Michigan Transportation Research Institute's Office for the Study of Automotive Transportation and representatives of the automotive industry. We assembled lists of prospective experts, then selected panelists on the basis of the position they occupy within the automotive industry and their knowledge of the topic being surveyed. They are deeply knowledgeable and broadly experienced in the subject matter.

The names of the panel members and their individual replies are known only to our office and are maintained in the strictest confidence. Replies are coded to ensure anonymity. The identity of panel members is not revealed.

The characteristics of the 74 panel members are as follows: 33 percent managers, 20 percent vice presidents, 16 percent directors, 11 percent engineers and/or senior specialists, 9 percent chief engineers, and 10 percent "other," including supervisors, leaders, and technical directors. The panel make-up is 56 percent suppliers and 44 percent manufacturers.

Presentation of Delphi forecasts and analyses

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

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

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

Our questionnaire also includes more traditional five-point scale items, and these are analyzed and reported in standard fashion.

Discussion. Narrative discussions are presented to highlight and explain a particular set of data. Where appropriate, statistical tests are relied on to inform and guide the discussion of the data and the interpretation of the results. Terms such as "different," "change," and "increase/decrease" are used where supported by the statistical analysis.

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

In a Delphi survey, respondents are encouraged to contribute comments to explain their forecast and perhaps to persuade other respondents to change their positions. Many of these edited comments are included. These replies may provide important information obscured in the numerical summaries of the data. An individual panelist may have unique knowledge that planners should carefully consider. However, readers should be cautious about relying too much on a particular comment. It is possible for a well-stated, but erroneous opinion to mislead readers. Care must be exercised in balancing individual comments and the summarized numerical data.

Manufacturer/supplier comparison. Panelists include respondents from North American automotive manufacturers; major suppliers of components, parts, and materials for the industry; and a few consultants and academics. A concerted effort is made to obtain an equal distribution of manufacturer and supplier panelists. In this report, we examine differences between manufacturers (or for brevity in tables, OEMs—original equipment manufacturers) and suppliers.

For obvious competitive reasons, the automotive manufacturers maintain a high degree of secrecy regarding their design, engineering, and marketing plans. While the relationship between the manufacturer and supplier is moving to a closer degree of cooperation and integration, considerable proprietary concerns remain. Additionally, the very size and complexity of the automotive industry works against optimum information transfer. Therefore, our analyses include a comparison of the forecast from manufacturer and supplier panelists in an attempt to illustrate where significant agreements or differences exist. Our tables only show the items where statistically significant differences between responses from suppliers and manufacturers were found.

Strategic considerations

This report makes inferences and interpretations as to the core issues and questions and their potential impact on the industry. While these are tied to the question replies, we also draw on other research and studies and OSAT's extensive interaction with the automotive industry. By no means do we think they are exhaustive statements of critical issues. Rather, we seek to raise and discuss points that the reader might usefully consider.

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CONTENTS

ACKNOWLEDGEMENTS iii

FOREWORD AND TABLE OF CONTENTS v

EXECUTIVE SUMMARY 1

I. OVERVIEW

1. General characteristics of the industry 5
2. Product-design-and-development cycle times for new platforms maintaining current hardpoints 11
3. Product-design-and-development cycle times for new platforms establishing new hardpoints 16
4. Sources contributing to cycle time reduction 20

II. ORGANIZATIONAL ISSUES IN PRODUCT DESIGN AND DEVELOPMENT

5. Interactions across organizational functions within respondents organization and industry as a whole 25
6. Basic elements of the product development process 29
7. Effectiveness of communication methods 32
8. Organizational barriers 35

III. VALUE: COST, TIMING, AND QUALITY IN PRODUCT DESIGN AND DEVELOPMENT

9. Sources of changing costs within respondents organization and industry as a whole 45
10. Impact of math-based engineering on cost and timing in product-design-and-development process 48
11. Factors improving quality 51

12a. Value and difficulty of using math-based engineering tools for vehicle design and performance 54

12b. Value and difficulty of using math-based engineering tools for engineering design 57

13. Effects of computer related tools, math-base engineering and process/ organization management on cost and timing 60
14. Potential effects of 50 percent in product-design-and-development time 63

IV. PRODUCT DEISGN METHODS AND STRATEGIES

15. Effectiveness of design approaches 65
16. Effectiveness of design methods 68
17. Sources of innovation 70
18. Factors influencing design systems 73

19a. Use of stylist's time in product design and redesign 81

19b. Amount engineer's design tools used for new design and redesign 84

V. SUPPLIERS' ROLE IN PRODUCT DESIGN AND DEVELOPMENT

20. Allocation of development resources 87
21. Supplier attributes which impact cost and timing 90

VI. **GLOBALIZATION ISSUES**
22. Challenges of globalization 93
23. Technology transfer and supplier localization 97

VII. **HUMAN RESOURCES AND TRAINING**
24. Preparation of engineering graduates for your organization in product-design-and-development 101
25. Education level needed for entry-level product-design-and-development engineers, currently and 2007. 103
26. Effect of training and retraining on improving productivity 106
27. Workforce skills needed over the next 10 years and appropriate training site 108

VIII. **PRODUCT DESIGN AND DEVELOPMENT ACROSS INDUSTRIES**
28. Difference of product development process in the automotive field and other high volume industries 111

APPENDIX 115

KEY WORD INDEX 117

EXECUTIVE SUMMARY

Overview

The Automotive Product Design and Development Delphi expert panelists forecast that today's already-severe overseas competition will intensify by 2002, demanding global vehicle development. They also forecast that vehicle manufacturers will increase the number of models, but base them on fewer platforms. They predict that significant supplier contribution to development, the early involvement of suppliers in the design process, and openness to new ideas will all better characterize the industry of 2002 than they do the industry of today.

Panel experts forecast manufacturers will reduce their product development cycle time by about 33% between now and 2007. They expect the Japanese manufacturers to require 4 fewer months in 2007 than do the U.S. manufacturers, and 6 fewer months than do the European manufacturers. For vehicles that maintain hardpoints from previous models, the panelists expect the Japanese manufacturers to reach 20 months by 2007, with their advantage primarily rooted in the design and development part of the cycle rather than the concept development stage. The panelists' forecast for vehicles that establish new hardpoints suggests that Japanese manufacturers will require 26 months, and maintain an advantage over U.S. and European manufacturers in both stages of the design cycle.

Panelists attribute the reductions in product development cycle time over the past few years to a number of factors. Most important among them are supplier capabilities, early and overall supplier involvement, and computer-aided analysis tools.

Organizational Issues

Panelists suggest that the various functions that participate in the product development process work together fairly well, both within their company and throughout the auto industry in general. But their responses suggest that the working relationships between styling and both purchasing and manufacturing are fairly poor. Traditionally, these functions are not located in either geographic or temporal proximity; that may account for these patterns, and indicate cross-functional development teams as a possible remedy.

The Delphi experts report that their companies today have a formal product development process monitoring system, but are less confidant that it is strictly observed or that management does not circumvent it. However, they feel more confident such a system will be in place and effective by 2002, but still indicate a bit lower confidence in management adherence. Communication between people involved in the development process is important to its success. Today, panelists believe that face to face meetings and co-location are the most important means, but by 2002, other methods of communication will become equally effective, including interactive computer tools/common databases and e-mail/internet.

The major organizational barriers to effective product development process are "soft" issues, like lack of coordination (often reflecting a lack of integrated planning), ineffective leadership and goal communication, rather than technical barriers. Time, staffing, and budget constraints are also a major challenge to product development effectiveness.

Value: Cost, Timing, and Quality in Product Design and Development

Panelists report that environmental standards, safety, product liability, and recyclability increase the costs of the product development process. These estimates hold for today and for 2002, for the respondents' own company and for the industry in general.

The panelists expect math-based or CAE (Computer Aided) engineering will reduce 2007 development process costs by 20% and timing by 28% compared to today. For improving quality, they attribute more importance to managing the process than to specific engineering tools. Coordinating or combining the right people, teams, and capabilities are especially critical.

By 2002, experts report that math-based engineering will have substantial value for vehicle design, especially for engine, body, transmission, and chassis components, and for safety/crash, NVH (Noise, Vibration, and Harshness), and durability/fatigue performance. For engineering design, panelists estimate high value for integrated analysis of systems, fatigue analysis, stress analysis, engineering feasibility, die design, rigid and flexible body dynamic analysis and combustion analysis. In general, they also estimate moderate to substantial difficulty in developing the appropriate math-based tools. However, in most instances, they estimate the difficulty in developing the tools is lower than the value gained they provide. Math-based engineering offers especially attractive value-to-difficulty ratios for body and chassis components and for stress and fatigue analyses.

Panelists rated the potential of a range of technologies or systems to affect the cost and timing of engineering design by 2002. They rated all as having the same or more effect on timing than on cost. They view large knowledge/data bases of past designs and off-the-shelf components, and the integration of design/manufacturing systems as having the largest combined impact on cost and timing. Manufacturers are more optimistic than suppliers about the potential of many of these technologies, possibly because of their greater experience with them. Panelists estimate that 50% reduction in vehicle product development time over the next ten years would be correlated with an increase in the use of rapid prototyping methods and analytical testing, and a decrease in the iterations and total number of prototypes.

Product Design Methods and Strategies

Respondents report that concurrent design, a well disciplined design and development process, and the integrated use of computers/software have improved the product design and development process in their organizations, and will yield more improvement by 2002, when a number of other approaches will also become effective. They rate design for manufacture and assembly, rapid prototyping methods, and value analysis as the most effective design methods within their organizations. They report that product and process innovation is primarily generated internally, and expect that to continue, although they predict innovation will increasingly come from collaboration with their suppliers.

Design criteria differ by system, although vehicle cost has substantial influence currently and in 2002 for all the rated systems.

- For body panels, the three most influential design criteria currently and in 2002 are aesthetics, ease of manufacture, and vehicle cost. Library of design concepts experiences the largest increase in influence.
- For chassis and suspension, the most influential criteria currently are performance, safety, and vehicle cost. By 2002, ease of manufacture joins these, and recyclability and standardized design show the largest increases.
- For engines and transmissions, the most influential criteria for both the present and future include performance, meeting government regulations, and vehicle cost. The shift largest increase in influence will be for recyclability.
- For interiors, the most influential criteria currently include aesthetics, vehicle cost, safety, and packaging constraints. In 2002, these criteria will be joined by ease of assembly and manufacture. The largest gain in influence will be by recyclability.

- For heating, ventilation, and air conditioning (HVAC) systems, packaging constraints, vehicle cost, ease of manufacture, and performance are the most influential, and will remain so in 2002. Standardized design will gain the most.

The number of manufacturer/supplier differences in these comparisons highlights the challenges suppliers face as they take on more design responsibilities and try to find appropriate balances across a large number of design criteria.

Panelists predict that the use of stylist tools will change by 2002, as computer-based drawing tools increase and manual drawing and sketching decrease. Use of clay mockups will decrease, and use of virtual reality will begin. Panelists predict less change by 2002 for engineering tools, with CAE tools and in-house engineering databases representing the bulk of usage. Training new employees and re-training current employees may represent a continuing challenge for employers because of the rapid changes that occur in the software industry.

Suppliers' Role in Product Design and Development

Looking ahead to 2002, panelists predict manufacturers will spend 20% less time on product design and development, and suppliers 40% more time. Outsourcing design and development for a large number of vehicle systems might make full vehicle integration more difficult, unless the information technology systems are in place to make the process seamless, thus protecting the quality of final product.

Panelists predict that supplier attributes and performance will affect product development timing more than cost by 2002. Panelists predict that experience in the automotive field will be the dominant supplier attribute affecting cost and timing , while the ability to suggest new ideas will be the most critical performance dimension affecting cost, and CAD/CAM/CAE and rapid prototyping capabilities most important for timing.

Globalization Issues

Panelists report globalization issues, such as cultural/language differences and technology transfer, currently pose moderate difficulty for their design and development process. They predict the difficulties will generally lessen through 2002 to 2007, although the protection of intellectual property will maintain the same moderate level of difficulty that it has today.

The challenge of technology transfer to suppliers in emerging markets raises a number of issues: the availability of the appropriate technology in the local market and a supply of adequately trained technical workers; language and cultural barriers; the ability to maintain quality standards, and the protection of intellectual property.

Human Resources and Training

Panelists think the preparation in mathematical and analytical skills for engineering graduates is just about right relative to the entry-level needs of their organizations, but they think there is too little emphasis on hands-on experience, physical reasoning and synthesis skills, and knowledge of various manufacturing processes. Since the typical engineering program now takes nearly 5 years to complete, the challenge of balancing university and on-the-job training is crucial.

Panelists think that technical and managerial bachelor degrees match most entry-level product design and development engineer positions today, but predict that master degrees will be required for most of these positions by 2007. Panelists think that training in product design and development skills, personal development, and management tools improves productivity.

Panelists predict that a wide range of skills will be important to the industry by 2007. respondents report a number of skills that will be important to the auto industry. These skills include general skills such as communication, specific design areas such as reliability/safety, and technical skills such as manufacturing processes and finite element modeling and analysis (FEMA).

Panelists views of where these skills should be learned vary. They estimate that foreign languages and FEMA are best learned within the university system, while manufacturing processes, benchmarking, and many specific design areas may be better learned in-house. However, they feel most skills should be learned with a mixed university and in-house approach. Still, the large number of skills that respondents think appropriate for in-house learning will make significant demands on manufacturers and suppliers, who may be less well prepared for these activities.

Product Design and Development Across Industries

Panelists see the automobile as different from other medium to high volume industries, but by no means unique, since many of the differences they note are more a matter of degree than of kind. Respondents view the most important differentiating characteristics of the automobile industry as its product and market complexity, timing issues, safety and other regulatory constraints, styling concerns, and cost of investment and ownership. These characteristics describe other products, although they rarely occur in the same mix or to the same degree. The automobile industry must be open to learning from the experiences and efforts of other industries in areas such as modularization, system verification tools, or supply chain design and management. Indeed, fast adopters of new ideas from other industries may reap competitive advantage in the automobile industry.

I. OVERVIEW

Q-1. **Please consider whether each of the following statements is applicable in characterizing the general nature of product-design-and-development in the North American automotive industry currently and whether each may be applicable in five years.**

Scale: 1 = Strongly agree, 3 = Neither agree nor disagree, and 5 = Strongly disagree

	Mean Response	
Statements Describing the Auto Industry	**Current**	**2002**
Market related characteristics		
The industry is faced with intense overseas competition.	1.8	1.4
Competitive pressures demand global vehicle development.	2.2	1.7
The industry introduces new technologies every model year.	2.7	2.4
The industry offers an increasing number of option packages.	2.9	2.9
Design process related characteristics		
Suppliers make a significant contribution to developmental work.	2.3	1.6
Suppliers are incorporated early into the design process.	2.6	1.7
The industry is becoming more open to new design ideas.	2.6	2.1
Very streamlined design processes predominate.	3.5	2.4
The design process is characterized mostly by redesign with incremental design changes.	2.5	2.7
Cut-and-try methods are used too often (too many design iterations with prototype developments).	2.4	3.2
Increased time allows the development of effective designs.	3.1	3.2
Very little standardization occurs due to different design teams working on the same design at different time periods.	2.8	3.5
Other characteristics		
The industry is increasing the number of models while using fewer platforms.	2.4	2.1
The industry is reducing the number of vehicle platforms.	2.4	2.2
R&D is driven by company needs.	2.7	2.6
Developments are slow due to sheer complexity of the systems involved.	2.6	3.0
There is a prevalent "not invented here" attitude.	2.8	3.2
Important or urgent work is usually contracted outside.	3.7	3.7

Other responses:

- Highly integrated user friendly tools will be required for design-and-development: current, 3; 2002, 1
- Reduced lead times are tending to push out new technologies: current, 2; 2002, 1

Selected edited comments

Market related characteristics:

- 1) Brand management will result in a focused/targeted set of option packages. 2) Modular approaches will dominate at the systems level. 3) Standardization will occur on systems that do not differentiate.
- Competitive pressures will force major improvements in the vehicle design-and-development process. Regulatory climate will also play a huge role from now through early 21st century.
- Cost remains a driving factor.
- Increasing customer expectations will drive more customized vehicle choices, i.e. more option packages.
- For what I will control, the industry will offer more options and may be able to market them as "packages" to reduce manufacturing complexity. (Challenges will be engineering and verification complexity!)
- Standardization is definitely on increase and will continue, particularly on items that are transparent to final customer.
- There is a need for standard sizes across all auto manufacturers to cut cost – e.g., hose sizes!
- Time is the new competitive edge in auto industry.

Design process related characteristics:

- 2002 will see design iterations done very quickly on computer rather than with hardware as is done, to a large extent, today.
- Cut and try will be done on computer so many iterations can be done, but prototypes will not be used!!
- Cut and try will go away (expensive and time consuming), but more concepts may be sorted out up front. Different teams don't drive de-standardization by themselves, unfocused leadership does.
- There still does not seem to be an effective process to do global vehicle development, especially a process to define what can be common and what needs to be unique with accompanying development plans.
- Product design needs to continue to use computer technology in all areas and create network and training to support computer design.
- Restrictions on time prevent optimum designs. We must "over-engineer" to guarantee a safety factor.
- The root cause of all the above is lack of system engineering or QFD methodology. If good system design specs are done first, development and standardization follow easily and quickly.
- There is little standardization of vehicle interface, hence our products vary widely, especially across OEMs.

R&D characteristics:

- R&D is going away. It costs too much! There is more dependence on proven technology. Innovation is going south.
- R&D continues to be critically important, however, R&D will move more strongly into functional engineering groups and R&D must be done independent of vehicle programs. Vehicle development cycles moving to 18 months do not allow any R&D tied to a vehicle program.
- R&D is driven by customer needs.
- The key to success to get R&D to production faster and better is to improve focus on research to customer's unspecified wants, implement consistent invention methodology, develop parameter testing to understand product robustness, and teach correct product application. Have formal management sign-off of key phases from research to commercialization in production.

Discussion

The panelists agreed with the following statements as best characterizing the current general nature of product-design-and-development in the North American automotive industry.

- The industry is faced with intense overseas competition.
- Competitive pressures demand global vehicle development.
- Suppliers make a significant contribution to developmental work.
- Important or urgent work is infrequently done outside.
- Cut-and-try methods are used too often.
- The industry is reducing the number of vehicle platforms.
- The industry is increasing the number of models while using fewer platforms.

Panelists indicated substantially stronger agreement (more than half a scale point) with the following questions for 2002 than currently:

- Very streamlined design processes predominate.
- Suppliers are incorporated early into the design process.
- Suppliers make a significant contribution to developmental work.

Panelists indicated substantially stronger disagreement (more than half a scale point) with the following questions for 2002 than currently:

- Cut-and try methods are used too often.
- Very little standardization occurs due to different design teams working on the same design at different time periods.

Manufacturer/supplier comparison

There are statistically significant differences in the responses of manufacturers and suppliers for the following statements:

	Manufacturer Mean	Supplier Mean	Significance
	Current Year	Current Year	
Very little standardization occurs due to different design teams working on the same design at different time periods.	3.2	2.6	.034
Developments are slow due to sheer complexity of the systems involved.	2.3	2.8	.020
	2002	**2002**	
Increased time allows the development of effective designs.	3.6	2.9	.057
Very little standardization occurs due to different design teams working on the same design at different time periods.	3.9	3.3	.036

Strategic considerations

Panelists agree that the automotive industry today is faced with intense overseas competition, and believe that such intense competition will be even more characteristic of the automotive industry by 2002. These competitive pressures demand global vehicle development. This makes streamlining the design and development process critical for meeting the needs of different markets and segments in a timely fashion. Reducing design lead-time becomes a major success factor in this climate of increasing global competition. Even in the face of global vehicle development, duplication of efforts in the organization must be eliminated in order to increase efficiency.

One of the methods manufacturers currently use to address competitive pressures is the reduction of the number of vehicle platforms. Another key seems to be the offering of more models to cater to different global markets while using fewer platforms. This trend strongly suggests that the industry should modularize the vehicle subsystems by establishing a library of proven concepts, subsystems and components. Mass customization may not just be an option, but may become standard for those companies that will survive and maintain a competitive edge.

Suppliers currently make a significant contribution to developmental work, and this contribution will increase by 2002, although panelists disagree that important or urgent work is usually contracted outside. As competition in the industry intensifies, the manufacturer that makes the most effective use of suppliers, most effectively manages the number of vehicle platforms, increases standardization, and streamlines the design process will win share in the marketplace and maximize its profit. Panelists' comments also indicate that increased use of computers in the design process will speed iterations and reduce reliance on cut-and-try methods.

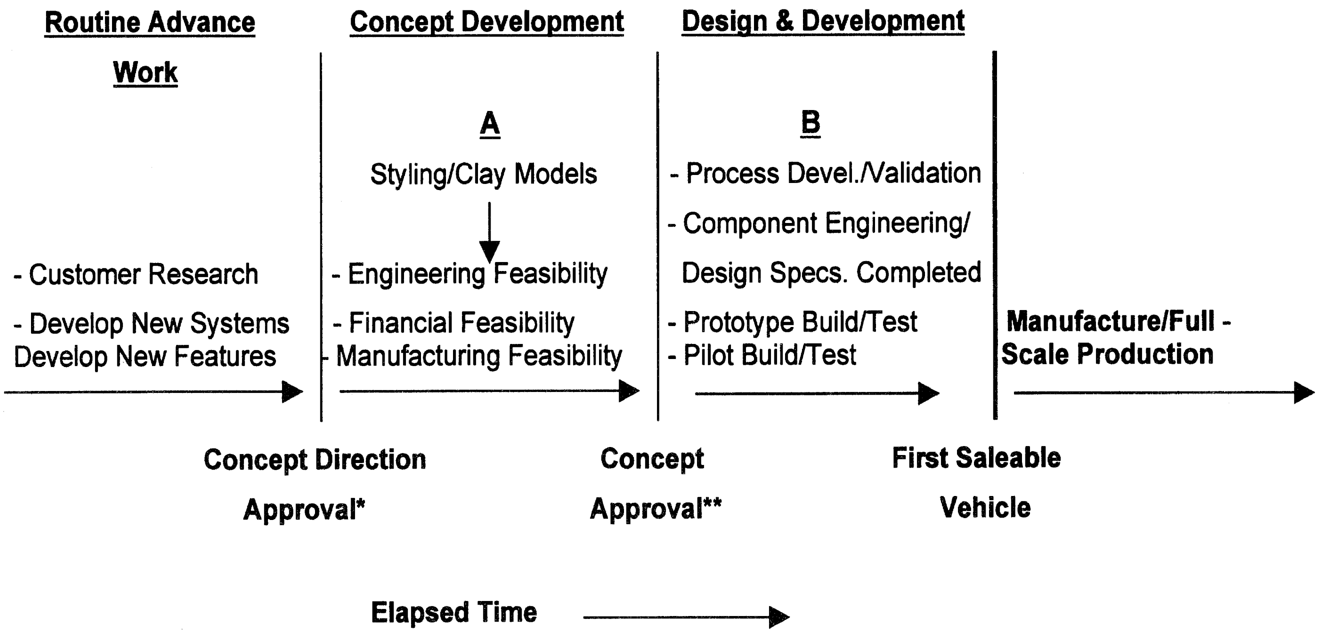
The nature and sourcing of R&D in the automotive industry is undergoing dramatic shifts, as reflected in the panelists' comments. While the comment suggesting that R&D may be eliminated because of cost is probably extreme, there is much uncertainty about its future. It is encouraging to note that the panelists believe that the industry will be more open to new design ideas in the next five years. This trend may be especially important in light of projected reductions in lead times and growing cost constraints on internal R&D.

Company needs should be the primary driver of its R&D. It is rather surprising that panelists do not more strongly agree that this is the case, nor reveal a trend in that direction over the next five years. When companies do not fund university research, it is understandable that the research does not directly address company or even industry needs. However, it is more difficult to understand why a company's own R&D efforts do not target the company's own needs. Moreover, it is critical that internal R&D personnel communicate and collaborate with individual divisions on a regular basis (without necessarily being tied to any particular vehicle program) to avoid both the impression and the reality of becoming just another "ivory tower," disengaged from the company's goals and mission.

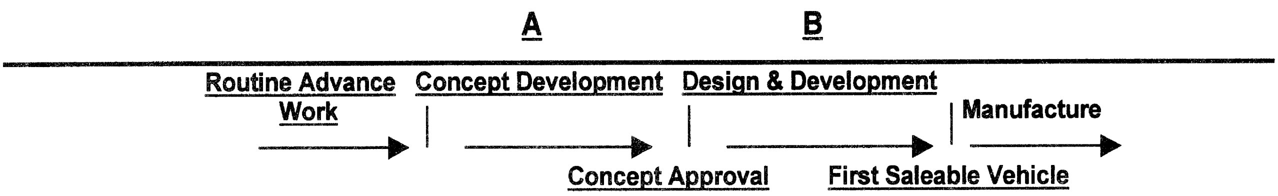
One OEM recently created a central warehouse for new technologies and new product ideas. This provides one-stop shopping for engineers, reduces duplication of efforts, and encourages creative solutions. Suppliers and other outside sources stock this "warehouse" for review by company employees. This seems to be a step in the right direction given the time constraints imposed on product development teams, and growing restrictions on R&D.

Manufacturer and supplier differences may be due to the different levels of complexity they face. The suppliers are more isolated and work with just one part of the system, while the manufacturers should have a wider view of the entire system. Interestingly, manufacturers disagree that increased time will allow for better design in 2002. Perhaps this reflects the increased time pressures they currently see, and the expectations that these time constraints will not ease in the future.

Panelists were asked to refer to the diagram below as they considered their answers for questions 2 through 4.

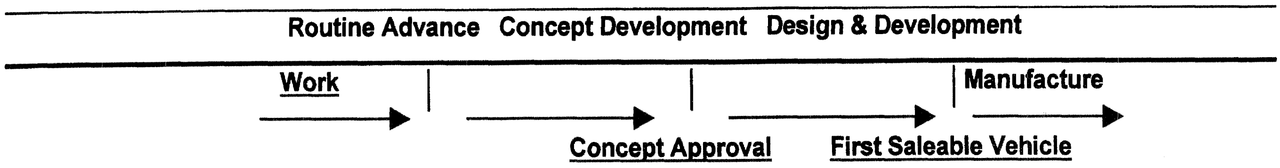


NOTE: For convenience, this abbreviated diagram was applied to additional questions later in the questionnaire:



***Concept Direction Approval:** The date that concept development resources and timing are approved.

****Concept Approval:** Approval by corporate management to take the vehicle to volume production, including the commitment of money and human resources. This approval follows demonstration of a model of the vehicle, a demonstration vehicle, and a verification of manufacturability and financial viability of the program.



Q-2. **Using the diagram above, please give your expectations, in months, for part "A" (Concept Development period) and part "B" (Design & Development period) of the product-development cycle. In this case, base your estimates on the hypothetical reskinning of high-volume vehicles, maintaining current hardpoints. Please estimate for current development cycles, and for development cycles in the years 2002 and 2007 for the manufacturers whose home base is in the geographic areas listed below *(e.g., GM-Opel and Honda of America would be included in your estimates for United States and Japan, respectively).***

	Median Response					
	Future Development Cycles					
Future Development Cycles Maintaining Current Hardpoints (more than 50,000 units/year)	**Number of months – (A)**			**Number of months – (B)**		
	Current	**2002**	**2007**	**Current**	**2002**	**2007**
United States	12	10	8	24	19	16
Japan	12	10	8	18	16	12
Europe	14	12	10	24	20	16

	Interquartile Range					
	Future Development Cycles					
Future Development Cycles Maintaining Current Hardpoints (more than 50,000 units/year)	**Number of months – (A)**			**Number of months – (B)**		
	Current	**2002**	**2007**	**Current**	**2002**	**2007**
United States	12/12	10/12	8/10	23/24	18/20	15/18
Japan	10/12	8/10	7/8	18/20	15/18	12/14
Europe	14/15	11/12	10/11	24/26	20/23	16/19

Selected edited comments

- Because of the complexity of the cars and all the systems that go together, I just don't think the development periods can reduce that aggressively.
- Concept development depends upon behavior and subjective issues. Remaining technological advances will not speed up much more. Design and development will benefit from more computer models, but not another 35 percent reduction.
- Development-cycle reduction will continue to be a major challenge for all manufacturers.
- Difference between U.S. and Europe will decrease over time.

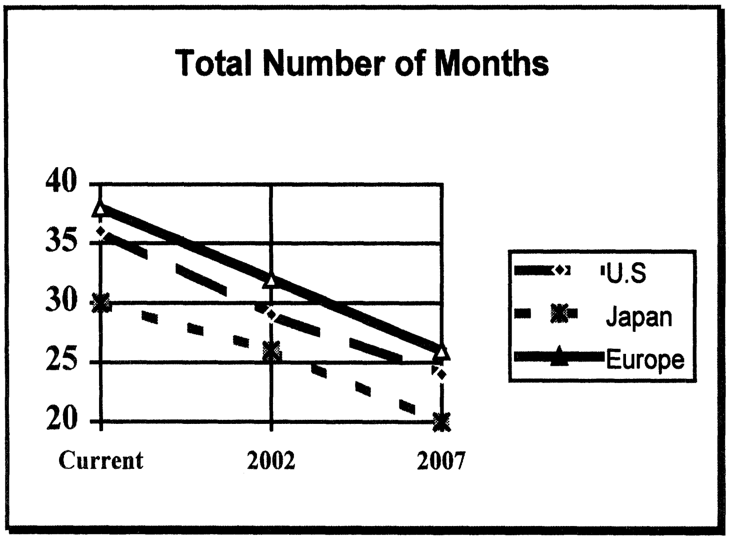
- In order to achieve a shorter development-cycle time for design, more time must be spent by cross-functional teams developing the concept early.
- It does not seem reasonable that significant differences in cycle time will continue to exist ten years from now.
- Some Asian platforms are reported to be all new, but may indeed have "hardpoints" very close to their existing models.
- The differences are more due to when the clock really starts. You eventually reach a point of diminishing returns – it doesn't matter how many women you put in a room, it still takes nine months to have a baby!
- The earlier tier-one suppliers are committed, the faster "B" will occur.
- The goal is to reduce the time to market for the period where big cash is spent (design and development) and tooling committed and executed. Since there is time left for recovery, selected concepts must be proven before a program is approved and the overall time between the two phases still has to come down. Each of the ways to achieve that present their own trade offs.

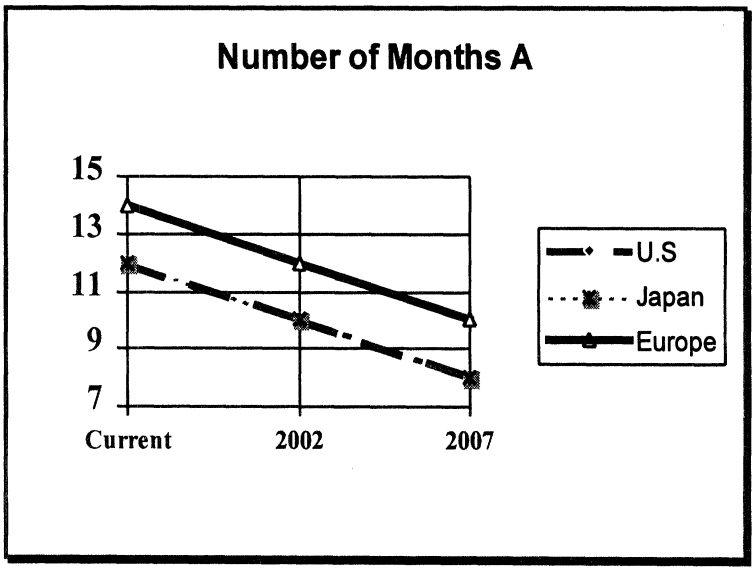
Discussion

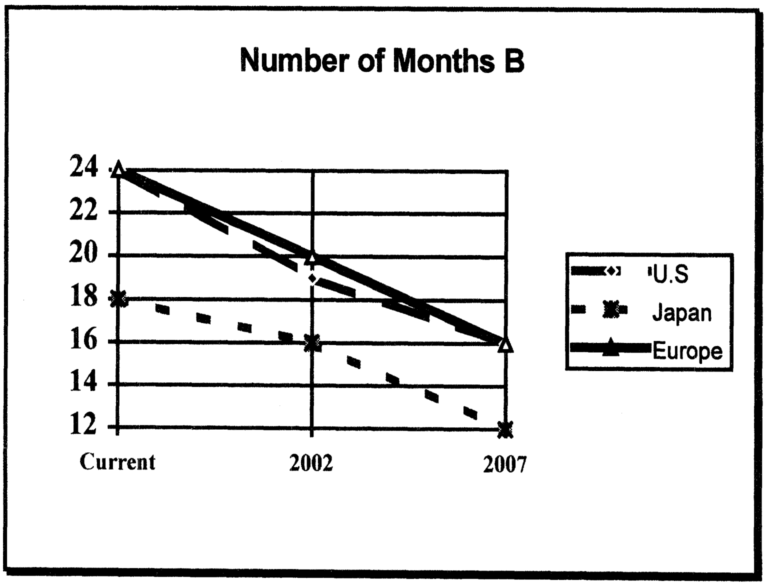
Panelists forecast that U.S., Japanese, and European companies will reduce their product lead times by 33 percent by the year 2007. Panelists indicate Japan and the United States have identical lead times for phase A. In phase B, Japan currently has a six-month shorter design-and-development stage than the United States and Europe, and this gap will reduce to four-months by 2007. As all companies strive to cut their product design-and-development lead times, panelists predict Japan's absolute advantage will be somewhat reduced, to four months. Note that the comparative gap by the year 2007 remains the same, as Japan still requires 75 percent of the U.S. and European required time. The percentage reductions are displayed in the table below.

Anticipated percentage reductions in phase A and B efforts

	Phase A	Phase A	Phase B	Phase B
	Year 2002	Year 2007	Year 2002	Year 2007
United States	16%	33%	21%	33%
Japan	16%	33%	11%	33%
Europe	14%	29%	17%	33%


Total Number of Months
40
35
30
25
20
Current
2002
2007
U.S
Japan
Europe


Number of Months A
15
13
11
9
7
Current
2002
2007
U.S
Japan
Europe


Number of Months B
24
22
20
18
16
14
12
Current
2002
2007
U.S
Japan
Europe

Manufacturer/supplier comparison

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

Strategic considerations

These panelist estimates require three important cautions. First, we recognize that the differences *within* national-based industries are growing even as the differences *between* them are shrinking. Therefore, readers should use these as general tendencies, rather than as accurate for particular companies in any of these industries. Second, some of the median differences are relatively small, and that should be kept in mind as well. It may be the case that such small differences reflect a few extreme company comparisons, rather than general industry capabilities. Third, in spite of our efforts to standardize terminology, there still may be definitional problems in these views, such as the starting point of the process.

In spite of the projected aggressive reductions in lead time by all manufacturers, the panelists see a continued Japan-based company advantage in design cycle time, rooted in the design-and-development stage rather than in concept development. The panelists must believe there is something fundamentally different about the way the Japanese system works to account for this continued advantage. As noted by one of the panelists, in the ordinary course of competitive development, it does not seem reasonable that Japan-based companies will continue to have such a lead-time advantage over the United States–based and European-based companies ten years from now. Competitive dynamics and the continued learning by the European and U.S. industries should largely eliminate this difference. If it does not, one might ask what this bodes for the overall competitiveness of these companies.

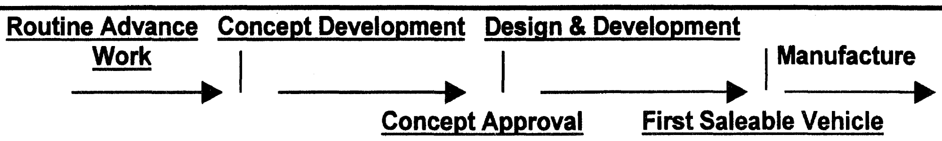
Part of the Japanese advantage could be the role of suppliers (see question 4 on supplier's attributes) and effective implementation of concurrent engineering (see question 15 on design strategies and approaches)

The key is to focus on phase-B activities, and a reasonable first step is to eliminate unnecessary design iterations. Some of the current design iterations result from poor communication (see question 8 (Organizational barriers), and this can be lessened by facilitating simultaneous development-team meetings among all functional areas.

Efforts should also target a reduction in the number of conventional prototypes tested. CAE and rapid-prototyping methods play an important role in assuring that the first functional prototype is nearer to production-ready. To be sure, rapid prototyping is not meant to replace computer-aided analysis and physical reasoning. It may be tempting to rely on rapid prototyping methods at the expense of a thorough and complete analysis. This could be particularly troublesome when parts produced by rapid-prototyping methods are not truly functional; however, these methods do help in understanding the packaging, assembly, and ergonomic constraints. Durability and performance should be estimated by computer-aided analysis and tested on functional prototypes.

Math-based engineering tools can profoundly reduce lead time and should be pursued at the level of component engineering. Some systems-level integrated-simulation tools are currently available, and as these technologies mature they too will have significant impact on future cycle time.

There is an important strategic balance issue that companies face in pursuing reduced product development time, and that is to ensure that it does not become a rote and ritualistic focus on time reduction at the expense of design innovation. This creative work should largely occur in the (here unmeasured) routine advance work and the concept development stage, where there are fewer differences across the three companies. Once the clock starts ticking on the concept development stage, invention should stop. It merits comment that the panelists estimate that the Europeans take longer at this stage, and it is the case that many, perhaps most enthusiasts credit the Europeans with the most distinctive and innovative designs. Companies should certainly pursue the continued shortening of the design cycle, but not through rote and uninspired repetition. Perhaps the staging and duration of legitimate routine advance work would be one route of pursuing innovation in a climate of intense pressure to reduce the cost burden of lengthy design and development stages.



Q-3. **Using the diagram above, please once again give your expectations, in months, of parts A and B of the product-development cycle. In this case, base your estimates on new platforms that establish new hardpoints for high volume vehicles, by geographic area. Please estimate for current development cycles, and for development cycles in the years 2002 and 2007 for the manufacturers whose home base is in the geographic areas listed below (e.g., GM-Opel and Honda of America would be included in your estimates for United States and Japan, respectively).**

	Median Response					
	Future Development Cycles					
Future Development Cycles Establishing New Hardpoints (more than 50,000 units/year)	Number of months – (A)			Number of months – (B)		
	Current	2002	2007	Current	2002	2007
United States	16	13	12	29	24	18
Japan	14	12	10	24	20	16
Europe	17	15	12	30	24	20

	Interquartile Range					
	Future Development Cycles					
Future Development Cycles Establishing New Hardpoints (more than 50,000 units/year)	Number of months – (A)			Number of months – (B)		
	Current	2002	2007	Current	2002	2007
United States	15/17	12/15	10/13	24/30	20/25	16/20
Japan	13/15	11/13	9/12	20/24	18/21	15/18
Europe	16/18	14/16	11/14	25/32	24/27	18/24

Selected edited comments

- As development times decrease, incentive and benefit of further reductions will decrease. Design tools (i.e., computers) will allow further decreases.
- Domestic OEMs (i.e., Ford and GM) will continue to reduce the total number of platforms.
- Europe seems to have caught the United States.
- The Japanese are at or near the optimum.

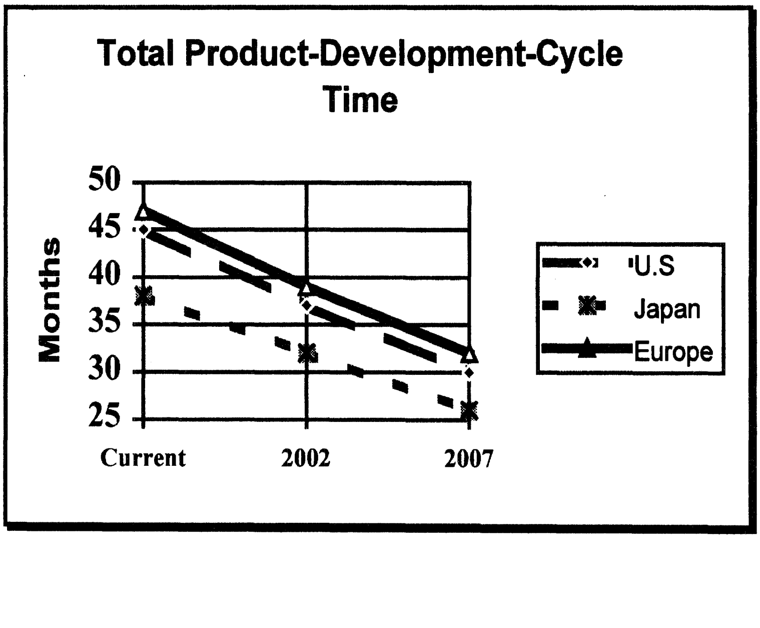
Discussion

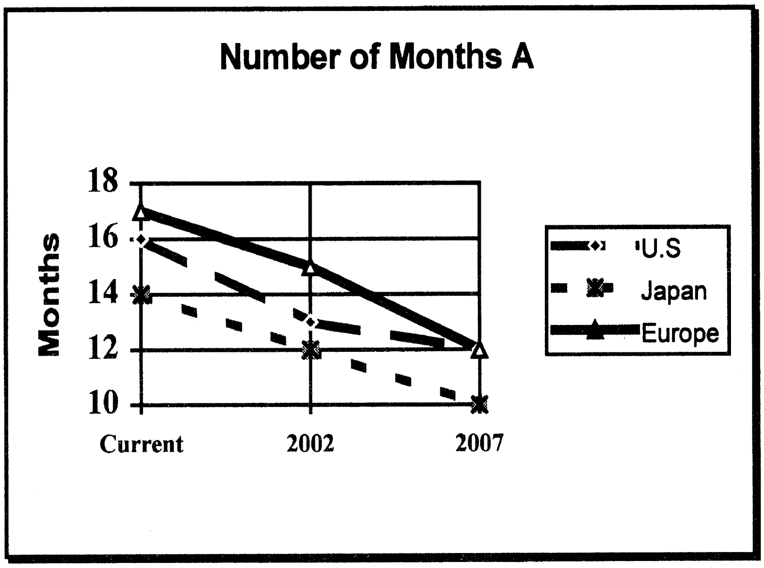
Japan-based companies *currently* take 2 months less to complete the preconcept approval stage (phase A) and 5 months less from concept approval to production (phase B) than do U.S.-based companies. The Japan-based advantage over the European-based companies, estimated by the panelists at 3 and 6 months for A and B, respectively, may be somewhat larger. Panelists forecast that the times for phase A will continually decrease in all cases, but Japan will maintain an advantage by the year 2007 of 2 months compared with the United States, and a possibly increased advantage of 4 months compared with the Europeans. However, the panelists expect the Japanese advantage in phase B to lessen by the year 2007, from the current 5 months to 2 months, compared to the United States, and from 6 months to 4 months compared with the Europeans.

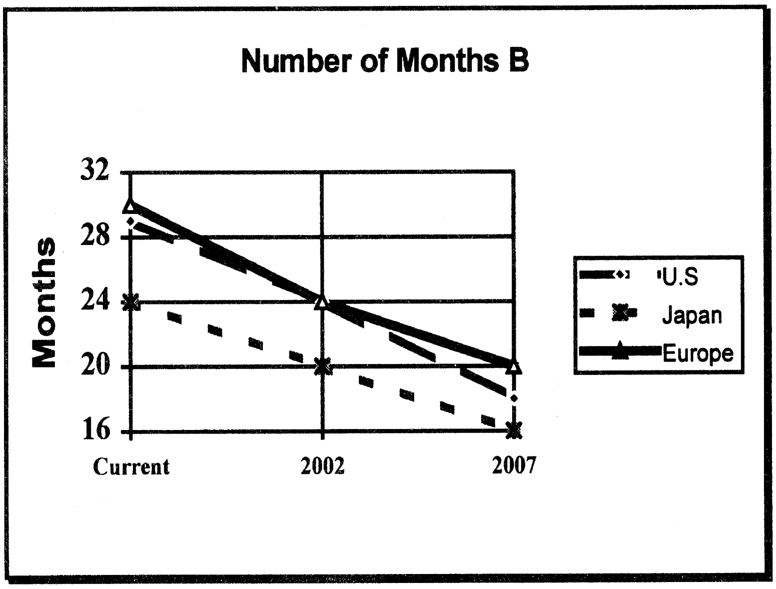
Anticipated percentage reductions in phase A and B efforts

	Phase A Year 2002	Phase A Year 2007	Phase B Year 2002	Phase B Year 2007
United States	19%	25%	17%	38%
Japan	14%	28%	17%	33%
Europe	12%	29%	20%	33%

Note that there is a somewhat greater percentage reduction projected in phase B relative to phase A. Our panelists forecast total reductions over the next decade of 12 months [(32 percent) for Japan-based companies, 15 months (33 percent) for the U.S.-based, and 15 months (32 percent) for Europe-based]. They expect Japan's product development lead-time advantage in the year 2007 will be 4 months against the United States and 6 months relative to Europe. Europe may currently trail the United States by 2 months, and panelists expect that difference to remain in the year 2007. These data are consistent with our findings in OSAT's Delphi IX technology forecast.







Comparing the results of this question with those of question 2 (Product-design-and-development cycle times for new platforms maintaining current hardpoints) reveals two consistencies. First, the relative improvements in product-development times are consistent across the stages and the industries: Panelists expect a reduction of about one-third in the time required for stage A and for stage B in each national-based industry, regardless of whether or not hardpoints are changed. Second, the timing differences between maintaining and changing hardpoints is 6 months for each national industry.

Estimated levels and percentage reductions by redesign extent

	Current hardpoints Year 2007	Current hardpoints Year 2007/1997	Change hardpoints Year 2007	Change hardpoints Year 2007/1997
United States	24 mos.	67%	30 mos.	67%
Japan	20 mos.	67%	26 mos.	68%
Europe	26 mos.	68%	32 mos.	68%

Manufacturer/supplier comparison

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

Strategic considerations

As discussed in question 2, cautious use of these estimates is appropriate, since differences *within* national industries are growing even as the differences *between* them are shrinking, some of these median differences are relatively small, and definitional confusion may exist.

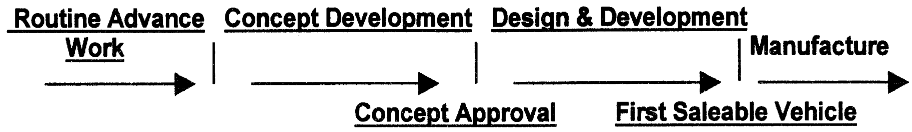
Reducing product-design-and-development lead-time is critical to bringing products closer to market demands and thereby improving market share. Large-scale redesigns, with changes in hardpoints, require more time than changes that work with existing hardpoints. Our panelists estimate this difference at 6 months, and do not see it differing as a function of where companies are based.

Currently the larger gap between Japan-based and U.S.-based companies is the 5 more months required by U.S. companies to complete phase B. This is also the larger gap between Japan-based and European-based companies, at 6 months. The panelists see this gap closing, to 2 months in the case of the U.S.–based companies, and to 4 months in the case of European-based companies. This is extremely important, because it is in phase B that commitments of money and manpower are so massive and therefore cost levels so high.

Some of the major factors contributing to these nation-based differences probably include the effectiveness with which Japan-based companies involve suppliers early and throughout the design-and-development process. These companies also reportedly standardize their designs more, especially through the use of carry-over designs and subsystems. In any case, the panelists see both these supplier and design efforts as important sources of recent and future time reductions, as discussed in question 4.

Other factors that may have direct influence on design lead-time include the facilitation, support, and commitment by upper management to cross-functional design teams, and the strict adherence to a formal process-monitoring system, as discussed in question 6. Another important source of time reduction is the effective use of virtual and rapid prototyping methods, as panelists mention in question 8 and rate in question 21. Finally, reduction in manufacturing set-up/ramp-up time is a critical capability for winning the competition along cost and time dimensions. This factor, along with design standardization, will become increasingly important as firms pursue mass customization to meet global market demands.

An important strategic issue is balancing the cost and time of product development. If time is reduced simply by increasing headcount, the added cost may exceed the value of the achieved time reduction.



Q-4. **Product-development-cycle time from concept approval through production of the first saleable vehicle (Design & Development) is reportedly shorter today than it has been in the recent past. In your experience, how important is each of the following possible sources to cycle-time reduction? How important do you expect each to be in five years? Please circle the most appropriate response, where**

Scale: 1 = Extremely important, 3 = Somewhat important, and 5 = Not important

	Mean Response	
Sources	**Current**	**2002**
Supplier Role		
Capability	1.9	1.3
Earlier involvement	1.9	1.3
Overall involvement/support	1.8	1.3
Standardization		
Carry-over design concepts (reusable design concepts)	2.1	1.7
Common databases between manufacturers and suppliers	2.4	1.7
Common hardware/software interfaces between manufacturers and suppliers	2.3	1.7
Carry-over subsystems	2.1	1.8
Reusable manufacturing facilities	2.3	1.8
Greater use of carry-over parts	2.4	2.0
Computer Tools		
Computer-aided analysis tools	2.1	1.3
Effective early cost estimation tools	2.6	2.0

	Mean Response	
Sources	**Current**	**2002**
Process and Organizational Management		
Better and more complete definition at program start	2.2	1.5
Cross-functional design and engineering teams	2.0	1.5
Application of Design for manufacturability (DFM) principles	2.5	1.7
Empowered organizational structure	2.4	1.8
Design complexity; proliferation of component-design variations	2.3	2.0
Organizational stability (people staying in their jobs)	2.2	2.0
Life-cycle engineering tools (serviceability, recyclability etc.)	3.0	2.5
Employee mobility	3.0	2.7

Selected edited comments

- Empowerment of organization to take risks and to take responsibility has far more impact than most people know.
- Teams that are most successful are ones that can effectively integrate all the above factors. We will continue to see commonization of business systems and components to increase efficiency of organization.
- With more talk of global vehicles, plant start-up support will be an issue.

Discussion

Panelists rate all of these sources as somewhat to very important in recent reductions in product development times. Moreover, they expect all except organizational stability to become even more important sources of time reduction by 2002.

Panelists estimate that the role of the supplier has been a very important source of cycle-time reduction, and will become an extremely important source in the future. On the other hand, while standardization efforts have been nearly as important as supplier efforts to date, and will also grow in importance in the future, they will be less critical than supplier efforts by 2002. Process and organizational management efforts have been somewhat important and move to very important for the future. Panelists differentiate the two computer tools, estimating that computer-aided analysis tools have been and will continue to be more important sources of time reduction in the product-development cycle than effective, early, cost-estimating tools.

Some of the more important specific items for the future are all three supplier efforts (capability, early involvement, and overall involvement), computer-aided analysis tools, better and more-complete definition at program start, and cross-functional design and engineering teams. All of these are rated extremely important for time reductions in 2002.

Manufacturer/supplier comparison

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

	Manufacturer Mean	Supplier Mean	Significance
	Current Year	Current Year	
Common hardware and software interfaces between manufacturers and suppliers	2.6	2.1	.050
Better or more complete definition at program start	2.4	2.0	.070
	2002	**2002**	
Carry over design concepts (reusable design concepts)	1.6	2.0	.046
Computer-aided analysis tools	1.1	1.5	.005

Strategic considerations

It is important to keep in mind that our panelists expect a reduction of about 16 percent by 2002, on the way to a reduction of about one-third in required product-development time by 2007, as outlined in questions 2 and 3 above. Consequently, we assume their views of how to achieve such sizable reductions reflect some careful consideration and thought on their part. To repeat an oft-used phrase in the performance-improvement community, the low-hanging fruit has been picked, and it behooves the picker to think about how to reap the high-hanging produce.

The panelists see the most promising package of efforts for reducing product-development times by 2002 in supplier capability and role. Based on responses to question 21, supplier capabilities include CAE, innovation, and systems integration. The role of the supplier includes establishing overall involvement with suppliers, and involving them as a part of the cross-functional product-development team from the outset. Furthermore, application of design for manufacture (DFM) principles early in the design-and-development phase can help develop products that are "production" right the first time, and thereby reduce the overall product-development time. To the extent suppliers will do the manufacturing, they will need to be selected and involved early in the process.

These new elements in the supplier role may require a fundamental change in the relationship between the OEM and its tier-one suppliers, both internal and external, in order to maximize reductions in product-cycle time. Specifically, suppliers will need to feel comfortable in sharing and participating in these activities, their costs, and their benefits. Attention will have to be focused on the role and relationships between Tier One suppliers and their own supply base as well, since these lower tier suppliers will do much of the actual manufacturing.

Manufacturing set-up and ramp-up time significantly affect the overall product-development time. Reusable, flexible manufacturing facilities can enable shorter ramp-up times as different products are introduced on an existing production line. Again, the involvement of suppliers throughout the design activity will become even more critical as they take on this greater responsibility.

Suppliers report that common interfaces between OEMs and suppliers and better definition at program start have been more important sources of current reductions than do the OEMs. This may suggest that suppliers, looking at their own responsibilities, are beginning to see the benefits that may ultimately accumulate to time reductions across the process for the entire vehicle. On the other hand, better design definition at the vehicle level may mean time reductions at the component level, reductions that may not decrease the overall elapsed time for the vehicle, although they should eliminate cost. Not all time reductions within the process will equally affect the time requirement of the total process, since parallel processes may vary considerably in their elapsed time, and only reducing the longest will shorten the total elapsed process time.

Panelists predict that standardization, in terms of carry-over design concepts, parts, and subsystems will play an increasingly important role in bringing quality products to market in a timely fashion. Again, there may be an issue of balance that must be watched carefully here, as discussed in question 2 (Product-design-and-development cycle times for new platforms maintaining current hardpoints). Essentially, balancing the cost-savings of standardization against the innovation of nonroutine approaches can be challenging and can vary from instance to instance.

The OEMs expect carry-over designs and computer-aided analysis tools to have greater importance in reducing product-development time in 2002 than do the suppliers. This probably reflects the differing complexity across the vehicle and its subsystems. Greater complexity at the vehicle level makes both these efforts more important sources, by eliminating more effort in the first instance and accomplishing more work more rapidly in the second.

Finally, adopting all the promising sources of product-development-time reduction identified by the panelists is itself a serious challenge. Not all of them are costly, and most of them are not likely to cancel the effects of other efforts. Yet they all represent change, and that itself makes pursuing all of them difficult. Changing the product-development process may itself be challenging in part because the means of doing it are themselves so daunting.

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II. ORGANIZATIONAL ISSUES IN PRODUCT DESIGN AND DEVELOPMENT DELPHI

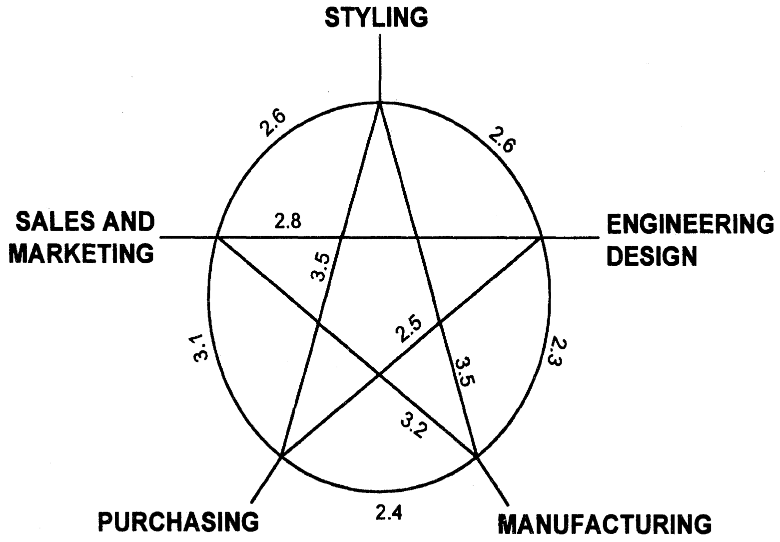
Q-5. How well do the following parts of your organization work together in product-design-and-development? Rate from 1-5, where

Scale: 1 = Work very well together, 3 = Work fairly well together, and 5 = Work very poorly together

	Mean Response			
	Styling	**Engineering Design**	**Manufacturing**	**Purchasing**
Engineering design	2.6			
Manufacturing	3.5	2.3		
Purchasing	3.5	2.5	2.4	
Sales and marketing	2.6	2.8	3.2	3.1

Selected edited comments

- All of these organizations could work well together but they typically have no formal process within product development that facilitates a good working relationship.
- Engineering design and styling are getting it together; it requires leadership both can respect. Engineering design is responsible for both product and process. Hence, a "single voice" helps to unite the groups (engineering and manufacturing).
- In general there is not a great deal of synergy across all four groups. However there is across pairs (i.e., engineering/manufacturing, engineering/purchasing).
- Interaction between styling and engineering continues to be a challenge, particularly with respect to timing.
- Styling remains separated from the system and continually ignores established criteria. It is the ultimate in free expression!
- The differences above are due primarily to separation of engineering and sales functions from manufacturing and purchasing functions.
- The traditional functional barriers are beginning to break down, but not quickly enough.
- We occasionally have a simultaneous engineering program with the customer. I would hope this type of program increases in the years ahead and we become more proficient.
- We need more input from marketing and sales on future product needs/wants.



Discussion

The data suggest some differences in the relationships among the various parts of the organization. While all the relationships fall within the fairly well range of the scale, there is a substantial difference between the highest and lowest scores. The relationships between styling on the one hand and manufacturing and purchasing on the other are more than a full scale-point below those between engineering design's relationships with manufacturing and purchasing. There may be some synergy between immediate neighbors in the circle diagram (average of 2.6), such as engineering design with manufacturing or styling with engineering design. This line can be compared with more remote relationships (average of 3.1), such as styling with purchasing or sales and marketing with manufacturing. However, this difference is largely due to the relationships of styling with manufacturing and purchasing, and may be better explained by the oft-noted separation of styling from the system in general.

Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers for three items. In each case, the manufacturer panelists report that their company's functions cooperate better in product-development activity than the supplier panelists report about their companies.

	Manufacturer Mean	Supplier Mean	Significance
	Styling		
Sales and Marketing	2.3	3.0	.033
	Engineering Design		
Manufacturing	2.0	2.6	.005
Purchasing	2.2	2.7	.031

Q-5a. **In your opinion, how well do the following functions in the auto industry work together in product-design-and-development?**

Scale: 1 = Work well together, 3 = Work faily well together, and 5 = Work very poorly together

	Styling	Engineering Design	Manufacturing	Purchasing
Engineering design	3.1			
Manufacturing	3.6	2.9		
Purchasing	3.6	3.1	3.1	
Sales and marketing	2.5	3.3	3.7	3.4

Selected edited comments

- Communications and politics are the biggest hurdles to overcome! Processes and time do not accommodate differing opinions.
- Styling remains an untouchable icon.
- With increasing interaction between different processes, the relationship between different organizations increases, but not as far as it is needed. How do you design for manufacturing if you don't know the manufacturing process capability? How do you partner with the extended enterprise and hit the sweet balance between OEM leadership and suppliers' early and continuous involvement, if engineering is not as committed as procurement and suppliers?

Discussion

When asked how various functions worked together in the auto industry in general, panelists indicated the situation is at about the same level or lower than it is in their own organizations, as described in question 5. The largest differences involve the relationships among engineering design, purchasing, and manufacturing, followed by sales and marketing relationships with engineering design and manufacturing. However, the panelists report that sales and marketing works relatively as effectively with styling in the industry in general as in their own company.

Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers for the items involving the engineering design, purchasing, and manufacturing triangle. Again, manufacturers estimate that these functions work better together than do suppliers.

	Manufacturer Mean	Supplier Mean	
	Engineering Design		Significance
Manufacturing	2.4	3.0	.009
Purchasing	2.5	3.4	.000

Strategic considerations

The data suggest that the traditional barriers have either been exaggerated or are beginning to break down. The panelists report that the different departments in their own organizations work fairly well together (Question 5). Moreover, if they believe their own companies are a bit ahead of the industry in general, they still report here that the industry is in the same range of the scale. In effect, if cooperation is not as good as it might be, it is certainly better than the conventional wisdom often portrays.

It is important that all functions work closely together particularly during the initial stage of a program, in order to define the design specifications clearly and completely. Styling has a major impact on the emotional response of the end-user, an important characteristic of the automotive industry. Styling affects the available three-dimensional space for all components, and poses significant design challenges to many vehicle systems (engine, transmission, HVAC, etc.) Therefore, it is very important that styling be tightly integrated throughout product-and-process development.

Rather than struggling with physical constraints thrown over the wall by styling personnel, product-development teams should be given the opportunity to participate in the initial styling activities. They can provide valuable input and negotiate the vehicle-space constraints without necessarily compromising the styling design, which should reflect customer preferences. A significant role and responsibility of management is to facilitate interaction among cross-functional teams early in and throughout the entire product-development process.

Differences between manufacturers and suppliers indicate that OEMs report better working relationships between some critical functions. This may reflect the fact that they have more experience with the complexity of product development and large organizations than suppliers. Different reports of their companies' working relationships between styling and sales and marketing may reflect the fact that many suppliers are in turmoil about product development because it is a relatively new challenge, and an area where they have new responsibilities and a changing role.

The differences between manufacturers and suppliers in the working relationships of the engineering design, purchasing, and manufacturing cluster are important. How well these functions work together at the design stage has tremendous importance for the timing, cost, and quality of the product throughout its life-cycle. The tighter relationships at the OEM level may be less valuable in terms of the overall vehicle if the weaker relationships at the supplier level result in less-than-optimal or even problematic parts, components, or systems.

Q-6. Please evaluate the following aspects of your organization's product-development process currently and for the year 2002.

Scale: 1 = Strongly agree, 3 = Neither agree nor disagree, and 5 = Strongly disagree

Current Product-Development Process	Mean Response Evaluation	
	Current Year	2002
A formal process-monitoring system is in place.	2.0	1.5
The process could be highly effective in principle.	1.9	1.6
The process is used uniformly throughout the organization.	2.7	1.7
The process is strictly adhered to.	3.0	1.9
The process is highly effective as practiced.	2.6	1.9
The process is supported by all parts of the organization.	2.8	2.0
Management does not circumvent the process.	3.0	2.3

Selected edited comments

A. Process still being developed/implemented (8)

- Component, subsystem, and system level activities are occurring currently, but not consistently across the entire vehicle or across different platforms.
- Currently our processes are being modified, and to predict that they will be used, adhered to, effective, or supported is purely a guess at this time. Also, our management is of such an age that by 2002 most will be retired, and new management will come in with entirely new and unique ways such that we may be in transition again.
- Currently we are restructuring the organization and combining three product-development processes into one.
- Formal process monitoring is being developed. Having an effective monitoring system that is common throughout the organization is critical to continuous improvement.
- Mindset is against the current systems applied in 2001 without improvements. (By 2002 a far more responsive program-management process will be required.)
- Our "productization" of systems began in early 1997. We are just developing a "process" for product development.
- The process is two years old and still being continuously improved.

- We currently have an unapproved ISO procedure in place and are using it as a guideline. As time goes by, it will be refined and implemented throughout the department. There will still be those rare occasions when the procedure would be circumvented.

B. System currently in place (3)

- Current development process is very structured and organized. Future process will be more efficient, but not different.
- The current system is working reasonably well; future vehicle system will be much more rigorous and common throughout organization; management is strongly supporting the process.
- We developed a process aimed at simplicity, sign-off, documentation, allocation of required resources, and mechanism to identify major issues to senior management. We also track planned versus actual date for completion of phases and weeks late in sign-off. Use charts to track engineering changes after production release to determine quality of process.

C. Process needs support of management (3)

- Adherence to the process seems dependent on leadership on the product.
- More effort needs to be directed towards the front end of the product-development process, obtaining buy-in across the organization and reducing management interference in the process.
- As a tier-one supplier, the biggest challenges to implementing an effective development process are 1) inconsistent or untrained engineers who lack a systems approach and 2) management that does not support cross-functional team concept.

D. Other (4)

- A change in the marketplace often requires flexibility in the OEM development process.
- Product data management (PDM) system is the direction of choice. In regards to real-time communication with "pull" versus "push" sequencing and full information sharing.
- There comes a time when the process becomes more important than the product. The MBAs lose sight of this. Most engineers by nature need free expression and formal processes stifle this. It becomes "cook-book" engineering. When failure occurs, no one knows why!
- Variability of customer wants must be accommodated. This limits the consistency of the product-development process. As customers refine their processes, I expect this discrepancy to decrease.

Discussion

The panelists agree that a formal process-monitoring system is currently in place, and that it could be highly effective in principle. They are much less certain that the process is highly effective as practiced, is used uniformly, or is supported throughout the organization. They are also uncertain that the process is strictly adhered to, or that management does not circumvent it. By the year 2002, the panelists are much more confident that an effective and functioning product-development process will be in place, but are somewhat less confident about management adherence.

Manufacturer/supplier comparison

OEMs and suppliers agree on all aspects except the two noted in the table. OEMs report their product-development process is currently more uniformly used and better supported by all parts of the organization than do suppliers.

	Manufacturer Mean	Supplier Mean	Significance
	Current Year	Current Year	
The process is used uniformly throughout the organization	2.4	3.0	.005
The process is supported by all parts of the organization	2.5	3.1	.018

Strategic considerations

The panelists agree that a formal product-development system exists now, but are more neutral as to how widely it is supported and followed. However, they expect substantial further change in their organizations' product-development processes by 2002. If the system is there, it is not yet completely implemented, nor is it receiving complete management support and endorsement. It is ironic that management puts the system into place and demands adherence, but does not necessarily itself follow the system. Nevertheless, the basic processes have been reengineered, so the work of the early 1990s is done. However, these processes have not yet been fully integrated into the organization's routine across departments or levels.

Companies need to recognize that designing the process, like designing the car, is only half the job. Just as the car must be built and sold, so the process must be integrated into the organization and subscribed to by all concerned parties. These new processes can be quite fragile, and if they are not quickly embedded into the daily routines of the organization and supported by the appropriate reward structures and decisions, they can disappear even more quickly than they were created.

Some of the comments suggest that management support is critical, and may alter as new managers replace current ones. Others note that these systems are rather new and will change over time as a function of continuous improvement, changing organizational needs, and market developments. Both these concerns are legitimate, but one must consider whether they describe real sources of change, or are simply the standard litany of excuses for failing to maintain the system, and circumventing it when it is personally or organizationally inconvenient. Management must discipline itself not to tinker with the process, nor continually circumvent it in the name of changing market demands. The market will always pose new challenges to the manufacturers and, in turn, they will pass some of those challenges on to their suppliers. Yet the effective implementation and maintenance of a well-defined, robust process is extremely important in responding to those changes.

The comment that ineffective engineers at the customer level are an impediment to the supplier's developing an effective product-development system highlights the extent to which these systems now span companies. A truly integrated product-development activity, like the value chain itself, will only be as strong as its weakest link.

Management must dedicate itself to seeing these systems effectively implemented and maintained, ensuring adherence to them across the organization by adhering to the system themselves. They must also be careful to separate the legitimate concerns and need for continuous change from mere attempts to avoid process discipline.

Q-7. Please evaluate the effectiveness of the following communication methods on product-development success currently and for the year 2002, where

Scale: 1 = Very effective, 3 = Moderately effective, and 5 = Ineffective

Communication Methods	Mean Response Effectiveness	
	Current	2002
Interactive computer tools and use of common databases	2.5	1.6
Personal face-to-face meetings	1.7	1.8
Collocating within a common work area	2.2	1.9
Internet/Intranet/e-mail	2.6	1.9
Simultaneous development team meetings	2.5	2.0
Video conferencing	2.7	2.1
Voice mail and fax	2.2	2.3
Virtual environment (video conferencing in combination with virtual reality)	3.4	2.4
Overnight mail	2.9	3.0

Other responses:

- Letters, prints, written actions: current, 1; 2002, 2
- Personal desktop video conferencing: current, 5; 2002, 3
- Simultaneous development team meetings: current, 1; 2002, 1
- Video phone: current, 5; 2002, 2
- Virtual environment (office/R&D): current 3; 2002, 1

Selected edited comments

A. Face-to-face (11)

- As we become more global, face-to-face meetings will become more difficult.
- Collocation, face-to-face, and voice mail represent 90 percent of all communications.
- Currently, design and manufacturing personnel are located in different buildings; plan to relocate in close proximity.
- Don't forget the interaction with product (hardware) in real situations and sometimes with real customers.
- Effective communication depends on familiarity and trust between people. This cannot happen without long term, face-to-face contact. In a global company, this means that greatly increased travel is a prerequisite.
- Face-to-face is an enabler for video conferencing. It doesn't work well unless there is an established relationship.
- Face-to-face is still better until the technology catches up.

- Team meetings can be very effective if run properly. More advanced technology is great, but often too problematic to result in a net gain in communication efficiency.
- QS-9000 requires development team meetings but our customers do not follow the program.
- The move from face-to-face contact will ultimately backfire with a who-dun-it approach to figuring failure.
- Too much time is spent on e-mail. We need more person-to-person communication to establish strong working relationships.

B. Electronic/e-mail, fax (8)

- Any action, which enhances the quality and speed of communication between functional areas, will improve the product development process.
- The common work area could be "virtual."
- Computer tools/e-mail/video conferencing are still in early development. Technology is there but training and equipment are not yet completed throughout the organization. This will continue to improve.
- Effectiveness of communication methods will increase not so much from improved technology, but more from understanding and acceptance by users.
- E-mail usage is abused. All communication should be for important information, current use of e-mail reduces effective communication. Faxes usually have important information.
- We hope to more effectively use these tools in the years ahead. We are currently going through a transition period with our department.
- Internet opportunities are effective now but the volume of transmissions in the future may preclude timely distribution of information.
- It lessens dependency on face-to-face where issues can be resolved. Electronic methods are impersonal, restrictive, and a major pain.

C. Video conferencing (4)

- More consistent application of videoconferencing throughout the North American and foreign organizations would improve communications effectiveness and lower cost.
- Team environment and tools (like video conferencing) that enhance ability to achieve team environment will cause improvements in product development success.
- Video conferencing is useful in the United States and Canada, but less useful in Mexico and other places.
- Video conferencing only works when relationships have previously been established. Strangers don't accomplish much by video.

Discussion

Not surprisingly, panelists indicated that personal face-to-face meetings are the most effective means of communication, falling in the moderate-to-very-effective range, while a relatively new technology, the virtual environment, is seen as the least effective, falling to the low side of moderately on our scale. Collocation, along with voice mail and fax lag face-to-face by about half a point. Simultaneous development team meetings, interactive computer use, communication nets and e-mail, video conferencing, and overnight mail all fall in the moderately effective range.

Each of these methods is expected to improve significantly in effectiveness by 2002, except for face-to-face meetings, voice mail and fax, and overnight mail. By 2002, collocation, interactive computer use, communication nets and e-mail, and simultaneous development team meetings are expected to be as effective as face-to-face meetings, with all edging towards the very effective end of the scale. Virtual environment will improve greatly, but will still be closer to moderately than very effective.

Manufacturer/supplier comparison

There were no statistically significant differences in the responses from the manufacturers and the suppliers.

Strategic considerations

The data and comments suggest that establishing methods that allow ample information and knowledge to understand, interpret, and assess the other party is a prerequisite for truly effective communication and relationships. Face-to-face meetings will continue to be effective means of communication in the next five years and an increasing number of organizations will probably make efforts to collocate various groups of individuals within a common work area because of the potential to enhance product-development effectiveness.

Although travel will likely continue to be a norm in the year 2002, once the working relationship is established, video conferencing and various computer-based communications media should prove to be effective, commonly used, and cost-effective supplements. However, video-conferencing allows a simultaneous exchange of ideas, the opportunity to observe the other parties, and permits the demonstrations of physical objects among a large group of participants. This technology, as it matures further, could play a very significant role in the near future in reducing travel time and costs, while improving productivity of all participants. Developments in virtual environment technology may even accelerate this trend to "remote-location" teaming.

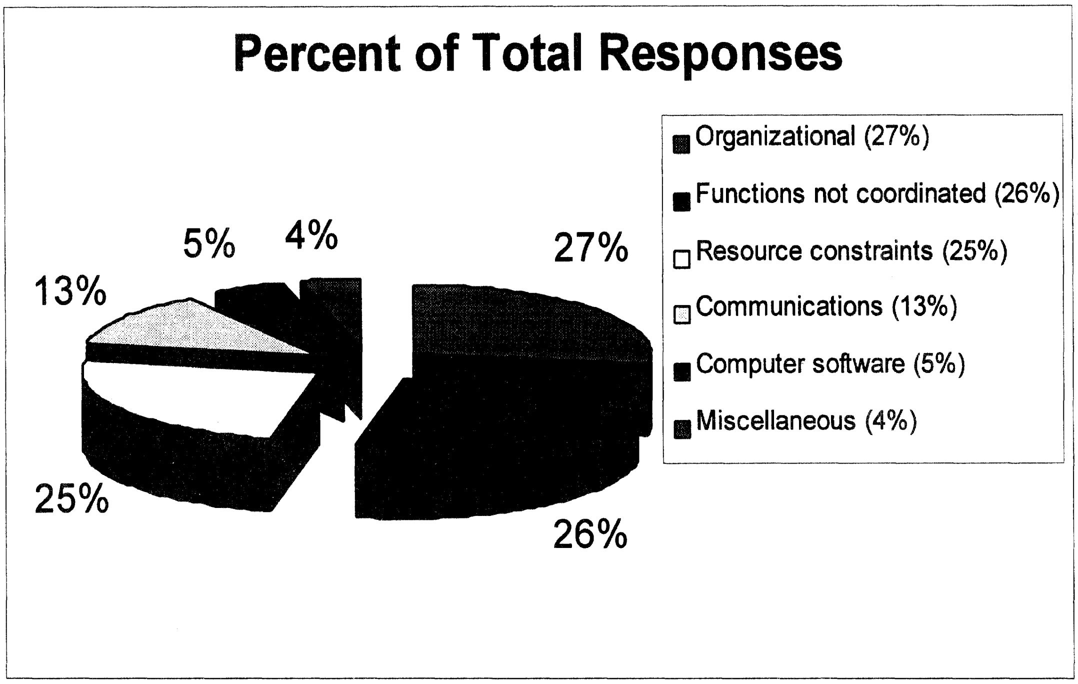
Impersonal electronic communications may be less effective for discussions and debates, although the electronic transfer or sharing of data (drawings, graphics, audio/video, etc.) via common databases can play a significant role in such product-development activities.

As noted in question 8, poor communication is an often-cited organizational barrier to achieving design-and-development-process effectiveness. It is difficult to over emphasize the significance of simultaneous development-team meetings in this regard. Such meetings can drastically reduce the product-development time and cost through reductions in the number of iterations, and they can improve quality (see question 11 for further comments on factors affecting product quality).

Q-8. **Please identify the three most important organizational barriers that reduce the effectiveness of the design-and-development process in your organization.**

Selected edited responses

Note: Each panelist identified the three most important organizational barriers that reduce the effectiveness of the design-and-development process in their own organizations. These responses were then grouped into six major types of barriers. The respondents' rankings (1,2, or 3) are maintained within these categories. Whenever a comment could fall into more than one category it was assigned to the least general group (i.e., if it was a problem of "communication" between organizational functions, it was assigned to the organizational category rather than the more general category of communication.)



I. ORGANIZATIONAL 2.1 (45)

rated 1:11
rated 2:20
rated 3:14

A. Lack of understanding of goals/ineffective leadership 2.1 (36)

rated 1:7
rated 2:17
rated 3:12

1) Competing priorities between current product improvement and future model development
1) Conflicting objectives and visions
1) Inability to focus proper resources at the proper time
1) Inconsistencies in the usage of design reviews and concurrent engineering. Senior management can and does overrule all of the design considerations, market research clinics, data analyses, and other information, in favor of narrow special interest, i.e., cost, styling, etc. These people need to be more accountable for their actions and outcomes.
1) Lack of discipline in commercial to sell what we have
1) Poor initial understanding of goals, poor direction

1) Span of control (number of programs or direct reports) in engineering is so large that effective design reviews are difficult to perform regularly.
2) Bosses caring more about moving themselves ahead than design concerns
2) Changing priorities on product development
2) Clear definitions
2) Corporate reorganizing, restructuring with changing roles and responsibilities
2) Focus on "quality imperative" is limiting "reach" in new product development
2) Lack of "buy-in" by some top level managers of cross-functional team
2) Lack of a unified program goal
2) Lack of culture that supports "people being our most important asset"
2) Lack of management support so that everyone should participate and cooperate
2) Lack of understanding of the design-and-development process
2) Lack of well defined priorities for new product development
2) Management discipline
2) Manufacturing and financial focus is a higher priority than design-and-development
2) Multiple accountabilities and lack of focus
2) Organizational "chimneys" – lack of team success attitude
2) Organizational objectives that are not consistent across the affected organizations
2) Poor statement of design goals
3) Incompetent leadership
3) Increasing levels of management approvals for product and manufacturing decisions
3) Lack of clear definition, understanding, and training of the roles of the OEMs and suppliers in the development process. *Editorial Comment: There is lots of talk about "full service suppliers," leveraging suppliers, tier-one suppliers, system suppliers, etc., etc. – but very little detail activity clearly defining who does what. There is lack of a "requirements flow down" process.*
3) Low potential for leapfrog innovation
3) Management program changes
3) Manufacturing's first priority is current production
3) Need a more effective process to identify, expedite, or kill new programs
3) No incentive to take risks
3) On time management decision
3) Things that work against teamwork; MBO management style
3) Too frequent organizational changes
3) Too many key people involved in too many activities, so time available for serious design review is limited

B. Attitudes and local culture 1.8 (9)

rated 1:4
rated 2:3
rated 3:2

1) NIH
1) Old traditions
1) The NIH syndrome
1) Things that work against teamwork, like our current "performance evaluations
2) Employee attitudes
2) Fear of andon pull
2) Individual personality clashes
3) Existing paradigms
3) Lack of teamwork

II. FUNCTIONS NOT COORDINATED 1.8 (41)

rated 1: 20
rated 2: 11
rated 3: 10

A. Lack of integrated planning 1.9 (27)
rated 1:12
rated 2:7
rated 3:8

1) Coordination of design, test, and CAE is not sufficient
1) Departmental reporting relationships – design versus fabrication versus assembly versus sales
1) Design departments too heavily focused on cost and weight vs. function and robustness.
1) Different design and release activities for components that fall within the same subsystem or system – lack of total subsystem ownership
1) Engineering and sales and marketing not working together
1) Lack of fully integrated system design specifications
1) Lack of good manufacturing input in design
1) Not enough multidisciplined interactions
1) Production doesn't want to get involved until they need tooling!
1) Specific product definition from sales and marketing
1) Groups' independently created design
1) Uncorrelated vehicle styling amond necessary evaluators
2) Competition between departments
2) Lack of complete vehicle specifications at program initiation
2) Lack of coordination between tradeoffs in design and adjustments in cost targets; fabrication and assembly (also resource availability/allocation)
2) No regular product-and-process evaluation meeting until recently
2) Poor communication among functions (styling, engineering, etc.)
2) Uncoordinated tinkering with design after design reviews
2) Unwillingness of production engineering to develop new processes and/or manufacturing technology
3) Constant product revisions
3) Effective system performance specification at the start of a program
3) Improved capability of earlier design maturation of interfacing areas
3) Inadequate communications with other suppliers and OEMS designing making parts and components.
3) Lack of coordination between product-design concept and tooling design
3) Poor measureables for design progress
3) Production representation processes and materials early in product development process
3) Targets (functional) not established up front

B. Geographic and cultural distance 1.6 (14)
rated 1:8
rated 2:4
rated 3:2

1) Bicultural organization causes all information to be pushed through two channels
1) Communication including languages
1) Geography
1) Lack of uniform process worldwide
1) Physical separation of key functional departments

1) Split sites: engineering and manufacturing at one site; sales, marketing, purchasing, accounting at another site
1) The physical distance (some are miles apart)
1) Working with overseas partners while travel and video facilities are limited
2) Cultural (we interact on four continents)
2) Multiple design-and-development locations
2) Physical distance between people
2) Styling department not located at same facility as engineering-and-design groups
3) Chief engineers not located at engineering site
3) Time (working across time zones can delay decisions)

III. RESOURCE CONSTRAINTS 2.0 (38)

rated 1:15
rated 2:11
rated 3:12

A. Time 2.1 (19)

rated 1:6
rated 2:5
rated 3:8

1) Dynamic requirement setting (ineffective freeze)
1) Inability for sales and marketing to "freeze" design input
1) Lack of business systems that support reducing lead time for product development
1) New manufacturing processes not developed, if needed, in concert with new product design
1) Time pressures
1) Timing for prototype requirements
2) Drawing approval process is slow
2) Huge requirements for "scorekeeping" data. Engineers spend more time creating status reports than performing technical engineering work.
2) Late business award from vehicle OEMs
2) No time for new technology
2) Prototype tooling timing
3) Lack of dedication to following defined procedures and doing tasks (i.e., APQP elements) early enough in development process and completely enough
3) Lack of discipline to meet milestone dates
3) Lack of understanding of true time to complete new product development
3) Late selection of production sources
3) Manufacturing planning not done on time or timely
3) Rapid prototyping is not approved for all projects
3) Short development cycles
3) Speed of prototyping

B. Staffing 1.8 (13)

rated 1:6
rated 2:3
rated 3:4

1) Availability of individuals when needed
1) MBAs with little or no experience
1) Not enough designers to work on new projects

1) Qualified and experienced staff
1) Resource allocation
1) Staffing levels too low; people spread too thin
2) Excessive workload
2) Lack of proper staffing
2) Support resources not in the organization
3) Personnel: qualified people to design and test
3) Qualified designers
3) Recruiting and training of new engineers to support growth requirements
3) Too many trackers and beaters, too few engineers

C. Budget 1.5 (6)
rated 1:3
rated 2:3
rated 3:0

1) Commitment of development money for programs
1) Financial constraints – reviews
1) Management's inability to refuse requests from customers that increase workload – then simultaneously demanding reduced budgets and headcount
2) Capital to buy above and support additional overhead
2) Cost pressures
2) Budget constraints

IV. COMMUNICATION 2.0 (21)
rated 1: 8
rated 2: 4
rated 3: 9

A. General communication problems 1.9 (9)
rated 1:4
rated 2:2
rated 3:3

1) Lack of understanding (2)
1) Antiquated or nonexistent communication tools
1) Knowing where to get helpful information
1) Poor communication
2) Communication (4)
2) Manufacturing/source responsiveness
3) Communication.
3) Inefficient communications: a) face-to-face meetings that require 2-to-three-hour driving time; b) lack of proper training and etiquette for video conferences; c) voice mail being used inappropriately for issues that are either so unimportant that communication was unnecessary, or for issues that will eventually require a real-time conversation anyway; d) lack of proper training and etiquette in voice mail use that causes long messages due to repetition and non-value added monologue
3) Poor maintenance of historical records

B. Customer communications 2.2 (12)
rated 1:4
rated 2:2
rated 3:6

1) Not having design freezes to please the customers (2)
1) Clear statement of requirements from the customer
1) Different CAD and EDI system for each customer
1) Lack of customer usage data
2) Customer driven design direction changes
2) Variations in customer wants from year to year and program to program
3) Acceptance of "last minute" changes from customer
3) Assignment of primary responsibility for customer interface
3) Customer incomplete information for design purposes
3) Inability for customer to accept change/risk, new approaches
3) Inefficiencies in managing the design process to a customer's (deliverable) expectation
3) Information from the customer

V. COMPUTER AND SOFTWARE 2.3 (8)
rated 1: 2
rated 2: 2
rated 3: 4

1) Lack of common design software within OEM community
1) Use of internally designed software
2) Computer power
2) Computers are not used in all areas yet
3) Different areas in the organization use different software and incompatibility of data
3) Lack of tools (CAD, computers, etc.)
3) Lack of training and equipment to take full advantage of computers in all areas
3) Product information not sufficiently computerized

VI. Miscellaneous 2.0 (7)
rated 1:2
rated 2:3
rated 3:2

1) Engineering continued education – for new ideas
1) Testing capabilities: equipment
2) Design content of prototypes
2) Full service suppliers not completely capable
2) Improve the local development capability of transplant suppliers
3) Improper evaluation of prototypes
3) Testing, durability

Category	Percent of total responses	Percent Rated 1	Percent Rated 2	Percent Rated 3	Total
Organizational	27%	24%	44%	31%	100%
Functions not coordinated	26	48	26	26	100
Resource constraints	25	38	31	33	100
Communications	13	38	19	43	100
Computer software	5	25	25	50	100
Miscellaneous	4	29	43	29	100

Discussion

Each panelist identified up to three most important organizational barriers that reduce the effectiveness of the design-and-development process in their own organizations. These responses were then grouped into six types of barriers. These broader barrier categories, and their frequency of mention, are displayed below. (They are also displayed in the pie-chart and table in the comments section.)

Barrier Categories

1.Organizational attitudes (27.6%)
  - A. Lack of understanding of goals/ineffective leadership
  - B. Attitudes and local culture

2.Functions are not coordinated (25.8%)
  - A. Lack of integrated planning
  - B. Geographic and cultural distance

3.Resource constraints (24.5%)
  - A. Time
  - B. Staffing
  - C. Budget

4.Communication (12.9%)
  - A. General communication
  - B. Customer communications

5. Computer and Software (4.9%)
6. Miscellaneous (4.3%)

The categories for grouping the comments are not completely exclusive. For example, concerns about the failures to coordinate functions, problems with organizational attitudes, poor communications, and customer-interface issues can be placed in a number of categories. Readers are therefore advised to read the comments as we have coded them to ensure that they understand how we are using these categories in our discussion. The panelists identify these types of "soft" issues more often as barriers than they do resource constraints or technical problems.

About one-quarter of the panelists' responses cover organizational barriers, such as conflicting objectives and visions, constant reorganization, lack of leadership, and constraining attitudes, like the NIH syndrome.

Another quarter of the panelists' report lack of coordination of functions, often reflecting a lack of agreement on priorities, goals, and definitions. They indicate that early and inclusive planning does not occur, there is lack of understanding of each other's processes, a lack of coordination between departments, people are not collocated, and there are frequently contradictory pressures. They also report lack of teamwork and discipline to reach goals.

Resource constraints account for another quarter of panelist responses, focusing on inadequate or inappropriate personnel, as well as budget and time limitations.

The types of communication barriers cited by panelists include bad communication tools, generally ineffective communications, and various problems in the customer interface. Customer-interface barriers include the inability to get input from customers in the appropriate time-frame in order to avoid last-minute changes and too much variation in customer timing and demands.

Computer and software barriers reflect variation in software, incompatible software, and lack of computers or appropriate training.

Strategic considerations

The problems described in these categories overlap, but they also contribute to and amplify each other. The lack of coordination of functions and the negative effect of organizational attitudes contribute to poor communication. In turn, poor communication leads to conflicting visions and objectives, one of the major reasons that organizations do not always work well. Improved communication, through meetings, planning, and timely sharing of data, can allay some of these coordination issues. However, panelists also note many other organizational barriers, such as competing priorities and lack of consistent direction, which may require more complex structural solutions.

Organizational attitudes. The issue of unwanted and counterproductive intervention by management is considered in question 6, where the effectiveness of formal process-monitoring systems is discussed. The responsibility of management to facilitate and reward team efforts is also a related issue. Comments made in question 6 apply here as well.

Frequent reorganization seems to be a general tendency within the auto industry, as does frequent reassignment. This can and in many cases does disrupt the product-development process. Personnel most experienced in a relevant aspect of the development process are too often transferred to a different department exactly when their services are most needed. This deprivation of the knowledge and expertise base can be avoided only if management recognizes and rewards experienced personnel within their own department. Dampening reassignments will also improve the accountability of the product-development team members, since transfer often ends responsibility.

Functions not coordinated. It is not really surprising that companies as large and complex as the auto manufacturers and their suppliers experience frequent and sometimes severe difficulty in coordinating their activities across departments, programs, and functions. Nevertheless, it is a major source of inefficiency, especially in the product-development process, which inherently should be one of the better-coordinated efforts.

To be sure, the reader must keep in mind that these are examples of problems drawn from many organizations, and probably no single organization that had most of them would long survive. However, they can form a useful checklist basis for considering the strengths and weaknesses of any particular organization.

The geographic and cultural problems noted by our panelists will probably escalate for a while yet, before coming down in the next five to ten years as companies move up along the globalization learning curve. As indicated in question 22, our panelists do expect a gradual lessening of cultural and language barriers over the coming decade.

Resource constraints. Time is a precious commodity in the panelists' view, but they note that time also can be a trap for the unwary, as failure to coordinate, decide, and execute at the appropriate point can be very expensive and damaging to the product-development process. Human resources are a major concern, as panelists report that staffing levels are often too low and available staff insufficiently qualified for the task.

Poor communication is an oft-cited barrier to product-design-and-development. Fortunately, management can tackle it with reasonable effort. The ill effects of poor communication are too many to list but in the end it depresses performance on all three dimensions of product development: time, cost and quality. Collocating key personnel and facilitating meetings among members of simultaneous-engineering development teams can significantly improve communication.

Increased use of video-conferencing facilities can potentially save time and resources, especially as companies become more global. Use of this technology will gradually enhance its acceptance and its users' comfort levels, while fostering further advances in the technology, in line with panelists' expectations in question 7.

Panelists concerns about problems with the customer interface are probably the external equivalent to the concern that different functional areas are not well coordinated. These comments also highlight the important point that there are external as well as internal problems with communication. These problems can result in inaccurate, late, and distorted data.

Computers: Shared databases and knowledge bases can significantly benefit the product-development team not only in reviewing the current design but also in retrieving past designs and associated information on materials, manufacturing constraints, etc. Appropriate use of these databases may in effect be a virtual simultaneous engineering exercise. The goal here should not be to do away with face-to-face meetings, but to supplement knowledge sharing with computer networking.

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III. VALUE: COST, TIMING, AND QUALITY IN PRODUCT DESIGN AND DEVELOPMENT DELPHI

Q-9. Please provide your view of the effects of each factor on the cost of the product-development process in your organization. Using the scale below, please indicate your opinion for today and for the year 2002.

Scale: 1 = Major cost reduction realize or expected, 3 = No cost change realized or expected, and 5 = Major cost increase realized or expected

	Mean Response	
External Factors	**Effects on Cost**	
	Current	**2002**
Overseas manufacture	3.1	2.6
Global economy	2.9	2.8
Achieving market quality	3.1	2.9
Availability of appropriate labor supply	3.1	2.9
Regional or global trade pacts	3.0	3.0
Product liability	3.2	3.4
Recylability	3.2	3.4
Safety	3.4	3.6
Environmental standards	3.6	3.8

Other responses:

- Damageability/insurability: current, 3; 2002, 4
- Skilled engineers/design resource: current, 3; 2002, 1

Selected edited comments

- By 2002, skilled resources in total design will produce a rapid development cycle, allowing greater speed to market.
- The global auto industry will result in common requirements, allowing a broader ability to apply product and system technology.

Discussion

Panelists indicate that none of these factors is expected to have cost-reduction benefits currently, and only overseas manufacturing will shift substantially by 2002. On the other hand, safety and environmental standards currently raise product-development costs in their organization, and product liability and recyclability cost will shift more negatively as well by 2002.

Manufacturer/supplier comparison

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

Q-9a. **Please provide your view of the effects of each factor on the cost of the product-development process in the automotive industry, in general. Using the scale below, please indicate your opinion for today and for the year 2002:**

> Scale: 1 = Major cost reduction realized or expected, 3 = No cost change realized or expected, and 5 = Major cost increase realized or expected

	Mean Response	
External Factors	**Effects on Cost**	
	Current	**2002**
Overseas manufacture	2.8	2.9
Global economy	3.1	2.9
Achieving market quality	3.3	2.9
Availability of appropriate labor supply	3.2	3.3
Regional/global trade pacts	3.0	3.0
Product liability	3.6	3.8
Recylability	3.3	3.6
Safety	3.6	3.9
Environmental standards	3.7	4.2

Selected edited comments

- It costs more to design one global vehicle than one local-market vehicle, but less than multiple local-market vehicles (to cover each market).
- Quality is not free, but it is the highest return on investment when it is smart.

Discussion

Panelists indicate that safety, product liability and environmental standards adversely effect product-development cost currently in the automotive industry in general. They further indicate that these areas will have a greater impact on product-development cost by 2002, with recyclability expected to also have an adverse cost effect by 2002.

Manufacturer/supplier comparison

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

	Manufacturer mean	**Supplier mean**	**Significance**
	Current Year	**Current Year**	
Product liability	3.3	3.6	.064
Safety	3.9	3.3	.001
	2002	**2002**	
Safety	4.1	3.7	.041

Strategic considerations

It is interesting that the panelists see only one factor as a clear cost reducer, and that is the beneficial future effects of overseas manufacturing. However, they believe this will happen for their own organization, but not for the industry in general. It is also of interest that they see the industry in general currently experiencing the drive to achieve market quality as a slight negative for product-development cost. This negative effect will lessen by 2002.

Environmental standards, safety, product liability, and recyclability are forecast to have continuing adverse impact on the cost of the product-development process in the next five years. This presumably reflects expectations that regulation and/or standards will multiply or tighten. This may be affected by whether product-development functions go overseas and how being overseas influences product variation. Computers can be used effectively in many design-and-development aspects of these issues. It is likely that those making the best use of computers will have a cost advantage in these areas of design and development, perhaps particularly in the area of safety.

In addressing safety systems, finite element analysis and other CAE tools can be effective in sorting out possible solutions. However, as with all computer models, it is imperative that the models have been calibrated to actual test results, and the user must be familiar with the capability and limitations of the model.

Manufacturers are currently more concerned than suppliers about the effects of safety on product-development costs. Suppliers' heightened expectations for the cost effects of safety on product development by 2002 may reflect two factors: 1) their growing engineering responsibility and 2) their concerns about cost-sharing by the manufacturers, already surfacing in warranty issues.

Q-10. There is a growing interest in math-based engineering, or computer-aided engineering (CAE), to reduce prototype and testing requirements. What impact do you expect from this technology on the cost and timing of product development by the years 2002 and 2007? Please express as percentage reduction in cost and timing from current process.

	Median Response		Interquartile Range	
Impact of Math-based Engineering	**Percentage Reduction**		**Percentage Reduction**	
	Cost	**Timing**	**Cost**	**Timing**
By the year 2002	10%	18%	10/15%	10/20%
By the year 2007	20	28	15/25	22/30

Selected edited comments

Cautiously optimistic

- CAE is off to a slow start due to lack of accurate modeling. Over time, with proper complexity management, the impact of CAE will expand drastically.
- CAE will benefit cost and timing only if it is not used to make more late changes, faster, at lower risk. You still need discipline to freeze the design.
- CAE will have a powerful impact but will take longer to implement than predicted.
- Cost will come out faster than time.
- Development time will see high levels of reduction between "current" and 2007. However, development cost will not show a linear reduction (versus time).
- Demographics (age) of managers influence this. The "experienced" workforce is most comfortable with physical properties. "Gen X" people are more than ready for visualization of math data. The two groups are sometimes unable to have meaningful conversation. We still need to build confidence in models.
- Improvements in cost or timing are highly dependent upon maturity of component technology and complexity of system.
- Management still is not comfortable with 3-D representations. Cut-and-try executions are still required to convince management of concepts.
- A shorter design cycle may allow more testing.
- The largest potential cost advantage of simulation is to reduce the number of iterations required to achieve target performance levels.
- The proper use of simultaneous engineering could speed up this process if all available data on cost, mass, manufacturing complexity, warranty, etc. were put on the same database, and updated with the same frequency.
- Re-emphasize the supplier-model (simulation) linkage to other suppliers and customers.
- Supplier computer models for subsystems must be linked to major systems. In my example, we have very sophisticated system models for our component systems, but do not link to the base product designers' CAE. Normally, base product design occurs independently of the rest of its containing system as well.

- Vehicle-development timing improvements will require reductions in prototype testing requirements and require further reliance on computer-aided engineering.

Skeptical

- Computers can't tell if an exterior looks "good," only if it is correct. Our new systems are burying us in mountains of useless data.
- 2002 is just around the corner and I don't see that much change.
- I don't see the vehicle manufacturers reducing cost overall, just shifting cost to suppliers. They won't pay for prototypes, but demand perfect parts for production, so we pay for prototypes to assure the product is properly developed. Or they want prototypes off production tools in lead time only available for prototype parts.
- There is no substitute for hard parts.

Discussion

Panelists forecast CAE will bring substantial improvements in cost and timing by the year 2002, and further sizable reductions by 2007. They expect the effects of CAE to be greater for timing than for cost.

Manufacturer/supplier comparison

OEMs have higher expectations of CAE than do suppliers in terms of cost reductions, both by 2002 and by 2007. The panels do not differ in terms of its benefits for reducing time.

	Manufacturer Mean	Supplier Mean	Significance
	2002	**2002**	
Impact of math-based engineering 2002 (cost)	14%	11%	.024
	2007	**2007**	
Impact of math-based engineering (cost)	24%	18%	.006

Strategic considerations

Our panelists forecast that CAE is likely to help reduce design lead-time by as much as 28 percent in the next 10 years. That is important, since, as noted in question 3 (Product design and development cycle times for new platforms establishing new hardpoints), the panelists forecast that companies will reduce their product design-and-development lead time by 33 percent by the year 2007. The panelists report greater time than cost reductions. Since design and engineering cost totals less than 5 percent of the total vehicle cost, CAE's relatively greater effect on design lead-time is important. To be sure, in manufacturing, the cost savings of CAE are likely to be much larger than they will be in design.

CAE can be very effective if it is properly utilized. Finite element analysis (FEA) is a good example of the power of computer-aided engineering. FEA allows us to analyze complicated models for which it is often impractical, if not impossible, to develop a closed-form analytical solution. In fact, FEA is so powerful and can be so useful that it may well be the most misused engineering software available. This probably reflects the users' and their supervisors' lack of understanding of the basic underlying physical phenomena. It is unfortunate that so much emphasis has been placed on computer-aided aspects of engineering at the expense of understanding basic physical phenomenon. Many users misunderstand the real significance and the power of these tools and harbor unrealistic expectations.

Effective CAE technologies have software models validated by benchmarking representative test models against physical data. In many cases, an approximate solution is sufficient to execute the next design iteration, but it is critical to be aware of how close the software model approximations are. Although customers demand accurate models and software companies constantly struggle to provide them, it is difficult to over emphasize the importance of understanding the actual degree of approximation between a software model and reality.

CAE may permit designs closer to the optimal before creation of the first prototype. However, CAE still lacks the integrated tools that can model an entire system (for example, engine, valvetrain, powertrain, and the supporting structure) and analyze it in terms of various design criteria (for example, crashworthiness, combustion, valvetrain dynamics, natural frequencies, engine cooling, and vibrations). Such tools will have a profound influence on not only design cost and lead-time, but also on product quality. As firms outsource various components and subsystems to suppliers, such integrated tools play a very critical role in ensuring the merit of the overall system design. As panelists note, the CAE model can make it very tempting to create quick and easy changes on certain aspects of a design. However, if such changes are not propagated to other relevant parts of the design, the end results can increase cost, lengthen timing, and yield a quality disaster. Keep in mind that some of these required changes might not be so obviously relevant. For just these reasons, systems-level integrated CAE tools are necessary to trace the effect of a design change on the entire system.

The use of relational databases and computerized past designs can also significantly improve the cost, timing, and quality of the design by providing the design engineer with all relevant data exactly when he or she needs it, and in a usable form.

The comments indicate that while most panelists are cautiously optimistic or hopeful about CAE, only a few panelists remain skeptical about its value. Cautious optimism is probably the right note for the industry to strike: CAE in fact is neither the panacea some of its proponents claim it to be, nor the placebo some of its detractors believe it to be.

Q-11. Please provide your opinion regarding the importance of each of the following factors in improving quality. Use the scale below, where:

Scale: 1 = Extremely important, 3 = Moderately important, and 5 = Not important

	Mean Response
Factors	**Importance**
Process/Organizational Management	
Product design accommodating process design and process capabilities	1.4
All interested parties (purchasing, engineering, manufacturing, marketing, etc.) working together before the design is developed	1.6
Effective distribution of best practices throughout the cross-function product-development staff	1.8
Sharing of ideas between platforms/departments	1.9
Tools	
DFMA	2.3
CAE	2.4
Rapid prototyping	2.6
Virtual reality	3.5
Human Resource Management	
Individual teams working towards common goals in an effective manner.	1.6
Management being open to new ideas and entrusting the design and manufacturing issues to technical personnel	1.8
Stability of workforce	1.8
Higher levels of education and training of personnel (describe below)	2.2
Other	
Increased pressure to compete in the global market.	2.3

Other responses:

- Common measurements and objectives: 1
- Consistent standard manufacturing process from plant to plant: 1
- Culture shifts that make data the way we do business: 1; process control – assembly plant (understood and used): 1
- Educate in new tech apps: 1; train in use of obj tools: 2
- Global design criteria acceptance: 1
- Maintaining design freezes: 1; advanced product quality planning: 1
- Organizational commitment to quality: 1
- Solve the power struggles between plant and corporate level organizations: 2

Selected edited comments

A. Education/ Training (15)

- Deployment of APQP – training on philosophy and methods.
- Education in the fundamentals.
- Education will become more important as more and more design responsibility is shifted to the suppliers.
- Education and training: SPC quality system.
- Education/training in methods such as TQM and concept engineering help to focus the team on customer requirements and can add quality to processes.
- Education/training: Quality principles (DOE – Shanin, Taguchi), Lean manufacturing (Kaizen, SMED, Visual Factory, Kanban), Interpersonal skills/teamwork.
- Education/training: we have an internal training portfolio every new engineer must complete.
- Engineers must be exposed to more diverse disciplines than in the past (Reliability, DFMA, DOE, Shainin, etc.). For instance, engineers need an understanding of reliability and statistics long before a graduate level state course. We need to distill concepts into "cookbooks" and guidelines for our staff to help them apply these concepts.
- Higher levels of education do not necessarily improve quality. Higher levels of training in particular fields may significantly improve quality.
- I feel that team and process training will become just as important as technical training in the future for most positions, except future R&D, due to an increased reliance on best common practices and part design libraries.
- We need more training on quality tools and problem solving tools.
- We need to insure we create "technical experts."
- On "Higher levels of education and training of personnel" – definite lack of understanding of variation.
- Personnel must be statistical problem solvers and have basic understanding of robust engineering.
- We encourage all forms of education and training, specifically in our areas of expertise.

B. Other (4)

- Education is not a substitute for experience! In many instances it is a hindrance!! The real world ain't like the book!
- Personnel are rotated so frequently that just when an individual learns a job, he/she is moved! "Lessons learned" retention is frequently lost.
- "Profound knowledge" – Deming.
- Suppliers need to be included in all organizational factors.

Discussion

Panelist ratings suggest that the management of the product design-and-development process is a more important way of improving product quality than are particular design methods or tools.

Product design that accommodates process design and capability is rated extremely important for improving product quality. Cross-disciplinary teams are also rated a very effective means to improve quality. Of these tools and approaches, only virtual reality failed to be rated at least moderately important. Note that numerous panelists indeed commented on the importance of education in fundamentals, and training in teamwork and quality tools as critical to achieving higher quality products.

Manufacturer/supplier comparison

There are two statistically significant differences in responses between manufacturers and suppliers, displayed in the table below.

	Manufacturer Mean	Supplier Mean	Significance
Sharing of ideas between platforms or departments	2.1	1.8	.053
Individual teams working towards common goals in an effective manner	1.4	1.8	.009

Strategic considerations

The automotive industry now recognizes that perhaps the single most important factor in product development is communication. That is why this volume places such emphasis on sharing ideas among various disciplines early and throughout the design-and-development process. The panelists' ratings of the elements of process and organizational management certainly support that emphasis.

Education and training in principles and practices of quality engineering will significantly influence quality improvement in the long as well as in the short term.

Design tools such as CAE, DFMA, and rapid prototyping methods are moderately important sources of quality improvement, but the responses on effectiveness of virtual reality technology are more skeptical. This may be due to the fact that it is a relatively new entrant technology, and its value to quality improvement has yet to be demonstrated.

Quality function deployment served and still serves as one organizational tool to carry out cross-disciplinary discussions, to record key information, and to identify conflicting objectives. The next step is to transform this from a process into part of the culture. Management should also play a key role in facilitating the process of internalizing the concept of teamwork. One simple and effective means to facilitate the team approach is to maintain a stable workforce and, where feasible, avoid transferring at least the key personnel involved in a given program.

Q-12A. Please estimate the value, by the year 2002, of math-based engineering and the technical difficulties involved in developing effective tools, for each area of vehicle design.

Note: Value = reduced cost and/or elapsed timing; or increased quality, performance, or customer satisfaction.

Scale: 1 = Extremely valuable/difficult, 3 = Moderately valuable/difficult, and 5 = Not valuable/difficult

	Mean Response	
Vehicle Design Areas	**Value**	**Development Difficulty**
Components		
Engine	1.8	2.3
Transmission/driveline	2.0	2.5
Body	1.9	2.7
Interior	2.5	2.7
HVAC	2.5	2.8
Tire	2.7	2.8
Windows and doors	2.4	2.8
Chassis	2.1	2.9
Seating	2.5	2.9
Performance		
Noise/vibration/harshness	1.8	2.3
Ride/comfort	2.2	2.3
Safety/crash	1.6	2.3
Durability/fatigue	1.9	2.4
Handling/steering	2.3	2.4
Suspension/ride	2.2	2.6
Styling	2.3	2.6
Acceleration/braking	2.5	2.8
Automatic controls	2.6	2.8

Other responses:

- Damageability: Value, 2; Development Difficulty, 1

Discussion

Panelists see substantial value in math-based engineering and moderate to substantial difficulty in developing the CAE tools to exploit the approach. Four component areas seem particularly suited to math-based engineering: body, chassis, engine, and transmission and drivetrain. In each case, the difficulty of developing CAE tools is rated at least one-half a scale point below the value of math-based approaches. Three performance areas are particularly likely to benefit from math-based engineering: safety/crash, NVH, and durability/fatigue. Again, our panelists rate the difficulty of developing the tools as substantially less than the value they will yield.

Manufacturer/supplier comparison

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

	Manufacturer Mean Value	Supplier Mean Value	Significance
Safety/crash	1.3	1.8	.010
	Development Difficulty	**Development Difficulty**	
Suspension/ride	2.9	2.3	.066

Strategic considerations

Math-based engineering can add significant value to the product design-and-development process at only moderate levels of difficulty in developing these tools. This is particularly the case in those areas of vehicle design where adequate math models already exist to predict performance. These areas, and the aspects where math models do exist, include the body, with stress, strength, and formability analysis, along with assembly modeling; the chassis, with stiffness and weight analysis; the engine, covering performance, stress, and heat transfer; and transmission and driveline, with performance models.

Math-based simulation models to predict durability/fatigue, NVH, and safety (crash simulations) are some of the key technologies that can add important value to the product-development process by reducing cost and/or time, or by increasing quality, performance, or customer satisfaction. Moreover, the degree of difficulty involved in developing and computerizing the underlying mathematics to yield appropriate tools seems reasonably proportional to the value in many cases.

Engine and transmission components may have a longer history of math-based model development than HVAC and interior components. Additionally, modeling the intricate HVAC geometry and flow patterns and interior design parameters that are difficult to quantify makes developing effective tools very challenging for these areas. While most math models fail to capture completely the physical realities (intricate geometry, boundary conditions, turbulence, etc.), properly developed models do capture enough to provide excellent feedback on the first-order effects. Appropriate use of these techniques can provide valuable feedback to the designer, and guide the design process in the right direction.

Current math-based analysis models are somewhat limited in their capability to capture the physical reality of a system. The true geometry, exact fluid flow patterns, joint clearances, or a combination of these and other factors, such as material and dimensional uncertainty, present difficulties. An important issue that limits the precision of math modeling physical reality is the statistical variation inherent in mass-produced goods. Extending the current "deterministic" math models to stochastic models would add significant value to our models. This would allow the engineers to design quality into the products by coming to grips with design robustness—that is, designs that are relatively less sensitive to variation (manufacturing variation, material uncertainty, variation due to end-user, etc.)

However, even imperfect models can provide very useful feedback and guidance to an experienced engineer, although the predictions of stress levels, heat transfer, crashworthiness, etc., are only as good as the model. An experienced engineer, who either understands modern modeling methods or works very closely with someone who does, can derive meaningful conclusions from model output. Nevertheless, that experience, insight, and reasoning is critical. Computers and software engineers cannot solve all of the problems encountered in a real and complex application.

Most design problems are interdisciplinary in nature, so software programs that synthesize and mathematically formulate principles from multiple disciplines in ways that allow their targeting on a problem will provide great value to industry. Some of the key characteristics of a good CAE tool include scalability, robustness, a general focus that is easy to customize and target, and a good user interface.

Finally, the reader should again remember that the bulk of the savings associated with design improvements through the application of math-based engineering will likely come in manufacturing, rather than in the design activity itself. Optimized designs and fewer design changes will significantly reduce the costs associated with design-driven manufacturing problems.

Q-12B. Please estimate the value, by the year 2002, of math-based engineering and the technical difficulties involved in developing effective tools, for each area of <u>Engineering Design</u>.

Note: Value = reduced cost and/or elapsed timing; or increased quality, performance, or customer satisfaction.

Scale: Extremely valuable/difficult, 3 = Moderately valuable/difficult, and 5 = Not valuable/difficult

	Mean Response	
Engineering Design Areas	**Value**	**Development Difficulty**
General		
System synthesis	2.1	2.2
Engineering feasibility (verification tools)	1.8	2.3
Conceptual design	2.1	2.4
Reliability estimation tools	2.3	2.5
Evaluation of design for manufacturability	2.1	2.6
Manufacturing and assembly	2.2	2.6
Parametric design	2.1	2.7
Die design	1.8	2.8
Cost estimation	2.2	2.9
Dynamics		
Occupant dynamics	2.0	2.4
Fluid-flow analysis	2.2	2.6
Heat-transfer analysis	2.1	2.7
Rigid and flexible body dynamic analysis	1.9	2.7
Engine		
Combustion analysis	1.9	2.2
Tribology	2.4	2.7
Electromechanical design	2.2	2.8
Structures		
Fatigue analysis	1.7	2.6
Stress analysis	1.8	3.0
Integration		
Integrated analysis of systems involving stresses, fluid-flow, heat transfer etc.	1.6	1.6

Other responses:

- Complete design integration, metrology: 1 (Value, Development Difficulty)
- Trade-off analysis: 2 (Value, Development Difficulty)

Selected edited comments

- There is a definite tradeoff relationship between metrology and tribology that needs to be researched.

Discussion

Panelists rate math-based engineering as having substantial value across all the listed areas of engineering design. In most instances, the degree of difficulty involved in developing useful tools is less than the rated value the tools will yield. The areas where math-based engineering has the greatest potential value include integrated analysis of systems involving stress, fluid flow and heat transfer; fatigue; stress; engineering feasibility; die design; rigid and flexible body dynamic analysis; and combustion analysis. Unfortunately, three of these also involve relatively high degrees of difficulty in developing the appropriate tools.

Manufacturer/supplier comparison

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

	Manufacturer Mean Value	**Supplier Mean Value**	**Significance**
System synthesis	1.8	2.4	.065
	Development Difficulty	**Development Difficulty**	
Conceptual design	2.1	2.7	.051

Strategic considerations

Panelists rate the value of CAE tools for all of the engineering design areas between "extremely valuable" and "moderately valuable," covering a range of 1.6 to 2.4 on our scale. Panelists generally rate the difficulty of developing useful tools to support math-based engineering as having a lower degree of difficulty than the value they will provide. In fact, in 9 of the 19 areas, the value of CAE tools is rated at least one-half a scale point above the difficulty expected in developing the tools. However, three of the six areas where CAE potentially has the most value are also areas where it faces more tool development difficulty. These are integrated analysis of systems involving stress, fluid flow and heat transfer; combustion analysis; and engineering feasibility. For the first two, the degree of difficulty approaches the value of the development, reflecting the complexity and early stages of such tool development.

A properly designed CAE tool can substantially assist a skilled and experienced engineer to enhance design value, by amplifying its desirable attributes or by reducing its undesirable aspects. The auto industry needs CAE tools that allow quick and reasonably accurate analysis of a system's performance. User-friendly features that permit an engineer to perform sensitivity analysis or to make design changes quickly are essential.

It is not surprising that the panelists rated highest those tools that perform integrated analysis of systems involving multiple problem axes (stresses, heat transfer, etc.). To be sure, these are also the most difficult tools to develop, because it is so challenging to develop integrated analysis tools that are seamless from one function to another. Tools for predicting time-dependent attributes such as fatigue, reliability, etc., also add a significant value to the design-and-development process, and face less severe difficulty in development.

Some of these CAE tools require sophisticated users, raising again the challenge of finding qualified people. However, this problem should abate somewhat in the future, as better-trained users become available and simpler, more user-friendly interfaces with the tools are developed.

Once these CAE tools are developed and validated, confidence in the underlying models will increase, and their use could grow explosively.

Q-13. Please provide your opinion regarding the potential of each of the following technologies or systems listed below to affect the cost and timing of engineering design* by the year 2002.

***Engineering design: Definition of the form and material specification for all components and systems of the vehicle, including electrical. Form and material are specified to meet performance requirements for the component or system.**

Scale: 1 = Major reduction expected, 3 = No change expected, and 5 = Major increase expected

Technology or Systems	Mean Response Effects on Design Year 2002	
	Cost	Timing
Computer-Related Tools – General		
Rapid prototyping tools	2.5	2.0
Customized integrated software tools	2.6	2.1
User-friendly CAD tools	2.5	2.1
Computer networking	2.7	2.2
Standardized CAM tools & interfaces	2.6	2.3
Very large screen workstations	3.3	3.0
Computer-Related Tools – Math-Based Engineering		
Simulation technologies (crash, heat flow, dynamics etc.)	2.4	2.0
Simulation of manufacturing and assembly activities	2.4	2.1
Finite element analysis	2.5	2.2
Parametric design tools	2.4	2.2
Artificial intelligence/expert system/neural network	2.9	2.5
Statistical tools for design (design of experiments)	2.7	2.5
Tools for conceptual design	2.8	2.5
Virtual reality	3.0	2.7
Process/Organizational Management		
Large knowledge/data bases of company-specific components and systems (past designs)	2.3	2.1
Large databases of standard off-the-shelf components	2.3	2.1
Integration of design/manufacturing systems	2.3	2.1

Other responses:

- Design optimization simulation: cost effects, 1; timing effects, 1

Selected edited comments

- Simulation of manufacturing and assembly activities and virtual reality are the same in my mind if you want a benefit for assembly.
- The prototype cost may decrease (smaller number of development bodies). However, the engineering budget will increase (manpower and CPU time).
- The technologies and systems are only effective if managed properly.

Discussion

The panelists expect many of these technologies and systems to reduce the cost and timing of engineering design. However, they believe that all of the listed tools and techniques will have a greater impact on timing than on cost, with the exception of design of experiments. The panelists rate three process/organization management tools as the major sources, on balance, of cost and timing of engineering design in the next five years. These include two large knowledge/databases, one of past designs and the other of off-the-shelf components, and the integration of design and manufacturing systems. Simulation is also important, both for specific processes (e.g., heat flow) and for manufacturing and assembly activities. They also rate rapid-prototyping tools as especially effective in reducing engineering design time, although only moderately effective in reducing cost. The very-large-screen workstation is the only tool estimated to have no effect, or perhaps a mildly negative effect, on both cost and timing.

Manufacturer/supplier comparison

The manufacturers' and suppliers' responses to the following items are statistically different.

	Manufacturer Mean	Supplier Mean	Significance
Simulation technologies (crash, heat flow, dynamics, etc.) (Cost)	2.0	2.7	.002
Simulation technologies (Timing)	1.7	2.2	.012
Large databases of standard off-the-shelf components (Timing)	1.8	2.3	.013
Large Knowledge/data bases of company specific components and systems (past designs) (Timing)	1.8	2.3	.019
Tools for conceptual design (Cost)	2.9	2.5	.049
Rapid prototyping tools (Timing)	1.7	2.2	.053

Strategic considerations

Our panelists report that process-management tools that eliminate duplicate activities and integrate the design and manufacturing systems are the most promising methods and tools for reducing engineering design cost and timing by 2005. However, they expect most of the general computer tools (CAE) to reduce required times and a few of the math-based engineering tools to reduce both cost and time.

Investing in some CAE technologies and rapid-prototyping methods can reduce design lead-time and cost. The reader must keep in mind that we asked our panelists' views on the comparative (not absolute) value of databases and tools over the next five years. These judgements may reflect the fact that some of the established math-based tools, such as CAD and CAM, have been in place for a longer time than have the process management tools; they may therefore have already provided their major gains in cost and timing. Although refining these tools will continue to offer major benefits in cost and timing, the panelists expect the marginal effect of this refinement to be less dramatic than the further development of the newer process-management tools. On the other hand, the panelists are less sure of the potential impact of technologies that are still in their relative infancy, such as virtual reality, and the data seems to capture that uncertainty.

It is interesting to note that the manufacturers and suppliers have different views of the potential value of four of the most highly rated tools for time reduction. These include both large knowledge/databases (for past designs and off-the-shelf components), simulation for specific processes, and rapid-prototyping tools. We cannot say whether this more optimistic evaluation by the manufacturers reflects reality, based in the manufacturers' greater experience with the technologies, or simply the manufacturers' tendency to believe more in "techno-fixes."

The impact of some of these technologies on engineering cost will initially be somewhat offset by the capital investment and training they require. Since we only ask for forecasts over a five-year horizon, these responses may exclude overall gains expected in the longer term. However, as companies move up on the learning curve, we feel the cost reduction may increase and certainly could total large sums.

It is important to keep in mind that these technologies will almost certainly yield greater benefits in manufacturing than in engineering, where the improved designs they yield should lead to major savings and cost reductions.

The beneficial effect on timing of so many of these methods and tools cannot be ignored. Timing is critical, as it directly affects how quickly a company can introduce products that are of immediate value to customers.

Q-14. **How would a reduction in vehicle product-development time by 50 percent over the next ten years affect the following needs and practices of the automotive industry? Please circle your answer from 1-5, where**

1 = Significant increase, 3 = No change, and 5 = Significant decrease.

	Mean Response
Needs/Practices of Industry	**Effect**
Use of rapid prototyping methods	1.6
Amount of analytical testing	1.8
Engineering personnel required	2.6
Amount of tooling required	3.5
Amount of physical testing	3.6
Number of dies required	3.6
Total number of prototypes	3.9
Iterations of prototypes	4.1

Other responses:

- Design change budget: 1
- Product life: 5

Selected edited comments

- CAE rules here.
- From a practical standpoint, the above noted must happen to enable a 50 percent reduction in development time! If this happens, I expect that the product cycle would decrease proportionally!
- I would expect that as development times increase, the customer demand and the competition will require that we introduce new technology and features at a faster pace thus requiring more programs on a shorter cycle, i.e., requiring the same number of engineers in total.
- More future mode testing of components and subsystems, coupled with analytical modeling, must be done in order to get the next design "production" right the first time.
- New designs in North America will still require extensive testing and prove-out (beyond other markets) due to legal liabilities.
- Tooling times would have to drop dramatically.

Discussion

Analytic testing and the use of rapid prototyping methods would both increase substantially, while all others would decrease, ranging in degree from somewhat to substantially, if vehicle product development were to be cut by 50 percent in the next 10 years.

Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers for the item measuring the amount of physical testing, as shown in the table below.

	Manufacturer Mean	Supplier Mean	Significance
Amount of physical testing	4.1	3.3	.003

Strategic considerations

First, this question poses a sharp reduction of 50 percent in vehicle product-development time over the next decade. This is a steeper decline than our panelists expectations of 33 percent in questions 2 and 3, although certainly not unrealistic. Second, we must be cautious in interpreting these results because, as one panelist noted, most people think of these practices as sources of such a reduction rather than as effects.

In any case, panelists believe that a large increase in the use of rapid prototyping methods and analytical testing would accompany this level of reduction in vehicle product-development time over the next decade, while some smaller increase in the number of engineers would also likely occur. They forecast varying degrees of decreasing reliance on other practices, ranging from a smaller decrease in the amount of tooling to a larger decrease in prototype iterations.

Note that even if there is some small increment in engineering manpower, its effect on cost would be minimal, and almost certainly compensated by savings elsewhere in the shortened development process. If analytic testing increases, physical testing decreases to a lesser degree, perhaps due to stringent safety and product liability issues that face the automotive industry in general and the North American industry in particular. However, the same pattern holds for increases in rapid prototyping and decreases in the total number and iterations of prototypes. There may be an interesting pattern here: the new ways of doing things are taken on faster than the old ways are shed. It is unclear whether this reflects an inherent conservatism about change, or a thoughtful caution about how complete the transition to the virtual world will be in just a decade.

The need for rapid-prototyping methods will continue to grow exponentially as the firms continue to compete in bringing quality products to market faster. The benefits of rapid prototyping are being recognized, even though the resulting "products" are not themselves functional. We suspect this will lead many firms to focus on developing rapid tooling methods, which should lead to an even faster development of functional prototypes in the near future.

The total number of functional prototypes, hence dies and hard tooling, will decrease somewhat, reflecting the increased number of design iterations performed on rapid, nonfunctional prototypes. This will change the business opportunities and billable products for many companies in the industry.

The manufacturers generally have more experience with models and simulations than do suppliers, largely because of their extensive development, use, and benchmarking of simulation in the safety arena. We suspect that they see further reduction in the amount of physical testing simply because they have more general faith in the use of alternative methods.

IV. PRODUCT DESIGN METHODS AND STRATEGIES

Q-15. For each of the following design approaches or strategies, please evaluate their effects on product-design-and-development in your organization currently and their potential effects for the year 2002,

Scale: 1= Major improvement realized or expected, 3 = No change realized or expected, and 5 = Major impairment realized or expected

Design Approaches or Strategies	Mean Response	
	Effect	
	Current	2002
Integrated use of computers/software at all levels within your organization	2.4	1.6
Well disciplined design and development process	2.4	1.6
Concurrent design (engineering, manufacturing, etc.) with frequent face-to-face meetings	2.1	1.7
Integrated use of computers and software across the supply chain	2.9	1.8
Design progress measurement system	2.6	1.9
Use of robust design* procedures	2.6	1.9
Reduction in number of product variations	2.6	2.0
Freezing systems-level design specifications once the design process is initiated	2.8	2.2
Increase the number of design reviews	2.6	2.2

***Robust design:** A design that will produce a component or product that will meet all of the specifications for which it was designed. These specifications include cost, performance, appearance, quality, reliability and durability.

(Note: Respondents used this definition for their answers. We are, however, aware that the emerging definition for robust design is insensitivity to variations across design criteria).

Other responses:

- FMEA/FMA: current, 3; 2002, 1
- Management participation: current, 1; 2002, 1

Selected edited comments

- Damageability, repairability, insurability, and recyclability need to be added to the requirements and/or robust design parameters.
- Most of these tools are currently in place within our department. I would expect them to improve in the future.
- Overall progress in design strategies may be offset by increasing product differentiation worldwide, an interesting problem for a low-volume manufacturer.
- Robust design is still not practiced in a disciplined manner.
- Robust design will not work if costs are higher and the part is overdesigned.
- The number of product variations is very likely to increase over time (e.g., export models). However, this should not be a detriment to development.

- We are at a point where the process is more important than the product. The irony is that those defining the process have never done the job. It's like asking your barber advice on brain surgery!

Discussion

Moderate improvements in product-design-and-development are already being realized through concurrent design efforts with cross-functional face-to-face meetings. Some gains are also coming from the adoption of well-disciplined design processes and the integrated use of computers. The other design approaches and strategies are not yet yielding much improvement, but none of them are causing damage or impairment.

However, panelists expect these activities to bring some improvements in the next five years, and all will fall within a relatively narrow range of moderate improvements.

Manufacturer/supplier comparison

OEMs report greater current improvements in product-design-and-development than do suppliers through concurrent design practices and having a well disciplined design-and-development process. The OEM panel also expects greater effects from a well disciplined design-and-development process by 2002 than does the supplier panel.

	Manufacturer Mean	Supplier Mean	Significance
	Current Year	Current Year	
Concurrent design (engineering, manufacturing, etc.) with frequent face-to-face meetings.	1.9	2.3	.025
Well disciplined design-and-development process	2.1	2.5	.056
	2002	2002	
Well disciplined design-and-development process	1.4	1.8	.052

Strategic considerations

During the last decade, the auto industry has recognized the potential benefits of adopting various design approaches and strategies, especially if combined with a disciplined approach to product-development. Indeed, some of these approaches are already making headway in improving the product development process, notably concurrent design efforts, the adoption of well disciplined design processes, and the integrated use of computers. The data suggests that the impact of these strategies will increase through the next five years, and the approaches that have not yielded much benefit to date will offer moderate benefits by 2002.

In our view, it is unfortunate that the panelists report little benefit to date from freezing systems-level design specifications once the design process is initiated, and that they expect only moderate gains from such design freezes in the future. Of course, some of these problems are transferred from one organization to another. Suppliers in particular have to constantly battle with changing specifications from the OEMs while the development is underway. Again, concurrent design procedures with supplier involvement early in the process can alleviate these problems in the future.

Although the significance of robust-design procedures is generally understood, they are still not practiced as commonly and consistently as they should be.

Product variations, or part proliferation, will continue to challenge the product-development activity. This is particularly the case as companies reach for new global markets, because even world cars will have some different requirements. Other data suggest that many companies are addressing this issue by reducing the number of product variations without limiting customer choices. This trend is healthy and necessary. Increasing product differentiation can be effectively handled by (a) standardization, (b) mass customization using a standardized library of functional modules, and (c) differentiating the product variations as late as possible in the manufacturing process.

Senior management support alone may be necessary, but is probably not sufficient to implement these product-development strategies and approaches. Middle management must also buy into these new programs in order for them to be adopted effectively. Otherwise, personnel may simply go through the motions of the process (such as developing a design-process measurement system) without deriving its full benefits.

Integrated use of computers within organizations and across the supplier chain will enable better product-data exchange. This should yield near-major improvements as it supports coordinated effort, permits standardization, allows reduced costs, and offers improved quality. However, the human resources requirements and change demands necessary to secure its benefits will be enormous.

Q-16. Please provide your view regarding the effectiveness of the following design methods and aids in your organization,

Please respond only for methods which have been or are currently being used.

Scale: 1 = Very effective, 3 = Moderately effective, and 5 = Ineffective

	Mean Response
Design Method	**Effectiveness**
Design for Manufacture & Assembly	2.3
Rapid Prototyping Methods	2.4
Value Analysis	2.5
Design of Experiments	2.8
Quality Function Deployment	3.0
Design for Service, Repair and Maintenance	3.1
Design for Recyclability	3.8

Other responses:

- CAE: 1
- Design for insurability: 4
- Early cost analysis: 1

Selected edited comments

- Unfortunately, most of our value-analysis projects have been too late in the process. Suggestions to OEs for change usually don't happen due to complexity of implementing change at OEs. VA needs to be a part of the conception of the part or system, not as a soft or subtle way to get suppliers to reduce costs (i.e., price) to OEs.
- Value analysis has been a destructive force because its practitioners refuse to accept the engineering functional requirements.

Discussion

The panelists rate 6 of these 7 design aids and methods as between moderately and rather effective. The highest rated are design for manufacture and assembly (DFM&A), rapid prototyping, and value analysis, although the comments suggest some mixed reactions to the last. Design for recyclability is the only one rated to the negative side of the scale, as rather ineffective.

Manufacturer/supplier comparison

There is a statistically significant difference between manufacturer and supplier responses to design for service, repair, and maintenance, as shown below.

	Manufacturer Mean	Supplier Mean	Significance
Design for service, repair, and maintenance	2.8	3.3	.011

Strategic considerations

The number of respondents to each of these methods suggests that the industry is broadly familiar with them, and each seems to have a reasonably high implementation rate.

Our panelists report that rapid prototyping is one of the three most effective design methods in their organizations. This is consistent with their rating it as an important source of time and cost reductions in question 21, as well as with their similar reports in question 14. As the "Strategic considerations" review in question 14 indicates, rapid prototyping is an important and expanding method for improving the product-development process. However, it bears repeating that it should not be relied on to the exclusion of other, more appropriate methods for some activities in the development process.

Panelists rate value analysis as relatively effective overall, although the comments suggest that in some cases its practice has been less effective than its promise, and might even be a hindrance rather than an aid. Properly implemented value analysis should not be a barrier to accepting engineering requirements.

Our panelists rate design of experiments, on average, as moderately effective. Yet this approach can significantly influence all three development-performance dimensions—time, cost, and quality. Taguchi methods constitute a reasonable starting place for developing a proper understanding and implementation of design of experiments. Firms that cultivate these disciplines and understand the power of these methods can achieve major gains in global competition. The philosophy and practice of design of experiments is slowly gaining momentum and may be an untapped resource in many organizations.

Service and maintenance issues should be addressed in a systematic fashion early in the design phase to reduce warranty costs and customer inconvenience. Note that manufacturers and suppliers have significantly different ratings of this method, with manufacturers finding it more effective.

Recyclability, currently often given a cursory nod and treated as an afterthought, will probably become a more important consideration in the future. The pressures on recyclability may come from regulatory activity or from customers placing greater importance on this factor. Companies need to carefully consider the future effects of environmental concerns on greater customer acceptance of its products. Design for recyclability is quite new, and many firms may not be fully committing to it because of time and cost pressures.

Q-17. Please indicate the frequency with which each of the following sources is used by your organization to create product and process innovations, that is, to generate creative and practical ideas, currently and for the year 2002, where

Scale: 1 = Very often, 3 = Sometimes, and 5 = Seldom

Sources of Product and Process Innovation	Mean Response Frequency	
	Current	2002
Internally, i.e., within your organization	1.9	1.8
Collaboratively with your component suppliers	2.9	2.1
Collaboratively with your systems suppliers	3.0	2.2
Collaboratively with your materials suppliers	3.0	2.4
Universities	4.0	3.5
Independent research companies	4.3	3.9
Small companies or entreprenuers	4.2	3.9
Independent inventors	4.4	4.2

Other responses:

- Customers: current, 3; 2002, 2

Selected edited comments

- An increase in frequency with some sources will come more from suppliers diversifying into new product areas versus change in approach to current business.
- We will have to become better speaking partners (and listening partners) with all, but it will still be difficult for independents to break into the auto industry of the future with new, creative ideas.

Discussion

Panelists suggest that they currently use internal resources most often to generate product-and-process innovations, followed by collaborative efforts with their suppliers, and then by other external sources. By 2002, panelists see input from the other external sources becoming more frequent, and much more frequent input from supplier efforts. However, the relative ranking of the sources stays the same.

Manufacturer/supplier comparison

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

	Manufacturer Mean	Supplier Mean	Significance
	Current Year	Current Year	
Collaboratively with your component suppliers	2.6	3.2	.008
Collaboratively with your systems suppliers	2.7	3.3	.030
	2002	**2002**	
Internally, i.e., within your organization	2.0	1.6	.038
Collaboratively with your component suppliers	1.7	2.7	.000

Strategic considerations

It is not especially surprising that automotive manufacturers and suppliers rely on internal resources to create product-and-process innovations, and will continue to do so. After all, innovation is competitively important for both and, some would argue, even forms part of these companies' core competencies. At the very least, such developmental activities would be viewed as highly proprietary. Respondents report occasional collaborative work with their suppliers currently, and expect that to become more frequent by 2002. This is consistent with the view that suppliers should be more technically capable, especially as systems integrators, as covered in question 21 (Supplier attributes which impact cost and timing).

Other outside sources, such as universities, independent research firms, and small companies are probably used less often for a variety of reasons. Less frequent usage may reflect the difficulty these outside agencies have in working with the large and substantial entities that comprise the auto industry. While probably lessening, there are "not invented here" attitudes in the industry, and these can be blocks to working effectively with those the industry defines as outsiders.

However, it will become increasingly important for manufacturers and suppliers to look outside their own industry to keep up with innovation and ideas. Technology is moving so fast, while time and cost pressures will continue to dominate this fiercely competitive industry, and internal sources will be too busy bringing present ideas into production to have time to innovate. Openness to outside sources of ideas and innovations may be particularly critical when companies are cutting back on internal R&D and design lead-time to stay competitive. The increasing reliance on outside sources reflects the reality of innovation patterns today as well as the developing reality of redirected automotive R&D and engineering budgets in the face of competitive pressures.

Manufacturers see collaboration with suppliers occurring more frequently than do suppliers. Both the current and future dimensions of this difference may simply reflect the fact that the manufacturers' suppliers are increasingly that large and technically capable set called tier one or systems integrators, while the suppliers' suppliers are in general at a lower tier and capability level. A less optimistic interpretation is that tier-one suppliers, who dominate our supplier panel, are not treating their own suppliers the way they wish the manufacturers would treat them, but rather very much as they complain the manufacturers in fact treat them today. In either case, the growing disparity over time in use of suppliers may be a potential weakness for the industry's innovation efforts.

Suppliers report higher levels of internal reliance than do the manufacturers in 2002. This is understandable and even desirable if you believe the suppliers are a better source of innovation than the manufacturers, as technical expertise and responsibility shifts to them. This is less understandable and desirable if you believe that substantial expertise also exists in the suppliers' suppliers.

For the following question, please rate only for one system, that system with which you have the most experience.

Q-18. **In your view, how much do the following criteria currently influence the final design for the systems shown, and what will their influence be in 2002? Please indicate your rating, where**

Scale: 1 = Great deal of influence, 3 = Some influence, and 5 = No influence

Table-A

Criteria	Body panel	
	Mean response	
	Current	2002
Packaging constraints	2.3	2.1
Available development time	2.4	2.4
Library of design concepts	3.1	2.5
Standardized design features and parts subsystems	3.0	2.5
Ease of manufacture	1.7	1.7
Ease of assembly	2.0	1.9
Performance	2.7	2.6
Safety	2.2	2.1
Cost of repair	3.1	3.0
Ease of service	3.4	3.3
Vehicle cost	1.9	1.4
Recyclability	3.5	3.1
Aesthetics	1.7	1.6
Meeting government regulations	2.5	2.2
Reducing weight	2.0	1.7
Improving ergonomics	3.7	3.4

Selected edited comments (Table A)

- There is a continued push to add aluminum and reduce weight to meet a new round of fuel-economy regulations, particularly for light trucks.

Discussion (Table A)

For body panels, panelists think that aesthetics, ease of manufacture, vehicle cost, ease of assembly, and weight reduction currently have the most influence on final design, and they think these same factors will be the primary influences on body panel design in 2002. Panelists rate improving ergonomics, recyclability, and ease of service as the least influential body-panel design criteria currently and in the future. The largest gains between the current and future ratings are in the library of design concepts; standardized design features, parts, and subsystems; and vehicle cost.

Manufacturer/supplier comparison (Table A)

There are no significant differences in the responses of manufacturers and suppliers.

TABLE-B

Criteria	Chassis/Suspension	
	Mean response	
	Current	2002
Packaging constraints	2.0	1.8
Available development time	2.5	2.3
Library of design concepts	2.6	2.3
Standardized design features/parts subsystems	2.6	1.9
Ease of manufacture	2.1	1.6
Ease of assembly	2.2	1.8
Performance	1.7	1.6
Safety	1.8	1.6
Cost of repair	3.3	2.9
Ease of service	3.1	2.8
Vehicle cost	1.8	1.6
Recyclability	3.6	2.9
Aesthetics	3.7	3.4
Meeting government regulations	2.4	1.9
Reducing weight	2.1	2.0
Improving ergonomics	3.4	3.4

Discussion (Table B)

Panelists estimate that performance, safety, vehicle cost, and packaging constraints currently have the most influence on chassis and suspension final design, and they predict these same criteria, joined by ease of manufacture, will guide chassis and suspension design in 2002. Panelists rate aesthetics, recyclability, and improving ergonomics as the least influential criteria for chassis and suspension design currently and in the future. The largest gains in influence between now and 2002 are for recyclability, standardized design features, parts, and subsystems, and ease of manufacture. However, note that recyclability is still viewed as having less influence than all but two other factors.

Manufacturer/supplier comparison (Table B)

Suppliers think meeting government regulations and improving ergonomics currently have a greater influence on chassis and suspension design than do manufacturers, and these differences persist in 2002. Manufacturers and suppliers diverge in their views of the influence of vehicle cost and standardized design features, parts, and subsystems in 2002, with the manufacturers believing these criteria will have more influence on design than do suppliers.

	Manufacturer Mean	**Supplier Mean**	**Significance**
	Current Year	**Current Year**	
Meeting government regulations	3.0	2.0	.041
Improving ergonomics	4.3	2.8	.028
	2002	**2002**	
Standardized design features, parts, and subsystems	1.4	2.2	.035
Vehicle cost	1.1	1.8	.044
Government regulation	2.6	1.5	.053
Improving ergonomics	4.1	4.1	.041

TABLE-C

Criteria	Engine/Transmission	
	Mean response	
	Current	2002
Packaging constraints	2.1	1.9
Available development time	2.2	2.0
Library of design concepts	2.7	2.2
Standardized design features, parts, and subsystems	2.5	2.1
Ease of manufacture	2.1	1.6
Ease of assembly	2.3	1.6
Performance	1.5	1.3
Safety	2.2	2.0
Cost of repair	3.4	3.0
Ease of service	3.0	2.8
Vehicle cost	2.0	1.4
Recyclability	3.9	3.0
Aesthetics	3.5	3.3
Meeting government regulations	1.9	1.5
Reducing weight	2.3	1.9
Improving ergonomics	3.9	3.4

Selected edited comments (Table C)

- Increasing intervention among fuel economy, aerodynamics, climate control, engine cooling, thermal, emissions and packaging.
- Weight reduction is a key issue to improve fuel economy and system efficiency.
- Weight reduction will continue to be a major driver in design as CAFE pressures continue!

Discussion (Table C)

Panelists report that performance, meeting government regulations, and vehicle cost have the most influence on engine and transmission design currently and in 2002. Recyclability, improving ergonomics, aesthetics, and cost of repair are reported to have the least influence on engine and transmission design currently as well as in 2002. The criteria with the largest expected increases in influence on engine and transmission design by 2002 are recyclability, ease of assembly, and vehicle cost.

Manufacturer/supplier comparison (Table C)

Compared to suppliers, manufacturers estimate that performance currently has more influence on engine and transmission design, and vehicle cost will have more influence by 2002.

	Manufacturer Mean	Supplier Mean	Significance
	Current Year	Current Year	
Performance	1.2	1.9	.012
	2002	2002	
Vehicle cost	1.2	1.7	.051

TABLE-D

Criteria	Interior	
	Mean Response	
	Current	2002
Packaging constraints	2.0	1.8
Available development time	2.5	2.3
Library of design concepts	3.0	2.4
Standardized design features/parts subsystems	2.8	2.3
Ease of manufacture	2.3	1.8
Ease of assembly	2.3	1.7
Performance	2.3	2.0
Safety	2.0	1.8
Cost of repair	3.7	3.1
Ease of service	3.4	3.0
Vehicle cost	2.0	1.7
Recyclability	3.5	2.7
Aesthetics	1.7	1.4
Meeting government rRegulations	2.5	2.3
Reducing weight	3.0	2.6
Improving ergonomics	2.6	2.2

Discussion (Table D)

Panelists think aesthetics, vehicle cost, safety, and packaging constraints currently have the most influence on interior design, and these criteria, joined by ease of assembly and ease of manufacture will have the most influence in 2002. Cost of repair, recyclability, and ease of service have the least influence on interior design currently as well as in 2002. The greatest gains in influence on interior design by 2002 are in recyclability, ease of assembly, cost of repair, and a library of design concepts.

Manufacturer/supplier comparison (Table D)

Manufacturers estimate that safety is a more influential criterion for interior designs, both currently and in 2002 than do suppliers.

	Manufacturer Mean	Supplier Mean	Significance
	Current Year	Current Year	
Safety	1.3	2.4	.048
	2002	2002	
Safety	1.1	2.1	.043

TABLE-E

Criteria	HVAC	
	Mean response	
	Current	2002
Packaging constraints	1.8	1.8
Available development time	2.4	2.2
Library of design concepts	3.0	2.6
Standardized design features, parts, and subsystems	2.9	2.2
Ease of manufacture	2.2	2.0
Ease of assembly	2.4	2.1
Performance	2.2	1.8
Safety	3.1	2.7
Cost of repair	3.4	3.2
Ease of service	3.1	3.1
Vehicle cost	2.1	1.6
Recyclability	3.7	3.1
Aesthetics	3.2	2.9
Meeting government regulations	2.5	2.3
Reducing weight	2.9	2.6
Improving ergonomics	3.0	2.9

Selected edited comments (Table E)

- HVAC is driven by cost and customer satisfaction. It should include engine emission, reliability, durability, and economy issues.

Discussion (Table E)

Panelists think packaging constraints, vehicle cost, ease of manufacture, and performance have the most influence on HVAC design currently and in 2002. Panelists also think recyclability, cost of repair, and ease of service have the least influence on HVAC design currently and in 2002. The criteria that gain the most influence on HVAC design by 2002 are standardized design features, parts, and subsystems, recyclability, and vehicle cost.

Manufacturer/supplier comparison (Table E)

There are no significant differences in the responses of manufacturers and suppliers.

Other responses (Round 1):

- Ergonomics: current, 2; 2002, 2 (Interior)
- Mass: current, 2; 2002, 1 (Body Panel, Chassis/Suspension, Engine/Trans.)
- Current 3; 2002, 2 (Interior, HVAC)

Strategic considerations (Tables A-E)

Although overall product quality, cost, and time-to-market are the conventionally accepted routes to success in the automotive industry, the design priorities for each subsystem still vary according to its particular role and function. For example, aesthetic criteria are important for body panels, packaging constraints are very influential on HVAC and chassis and suspension design, and both are quite important for interior design. But the only criterion that panelists estimate is one of the most influential for each of the five systems is vehicle cost. Managers recognize and respond to the need to meet cost targets for their system. This focus on vehicle cost bodes well for cost containment and company profits, and perhaps for stable pricing for consumers.

Two other criteria become quite important in each of the five systems by 2002. These are ease of assembly and ease of manufacture. The enhanced future influence of these criteria may represent *serious changes* in the way parts and systems will be designed. Since the tendency to move work to outside suppliers remains strong, these criteria reinforce the need for manufacturers to involve suppliers early in the design process, as covered in question 4. It will be difficult indeed for them to meet these criteria if the assembly and manufacturing processes remain indeterminate until late in the process. Of course, the design might be sent out to the selected outside supplier as well, and that would certainly permit designing to these production criteria.

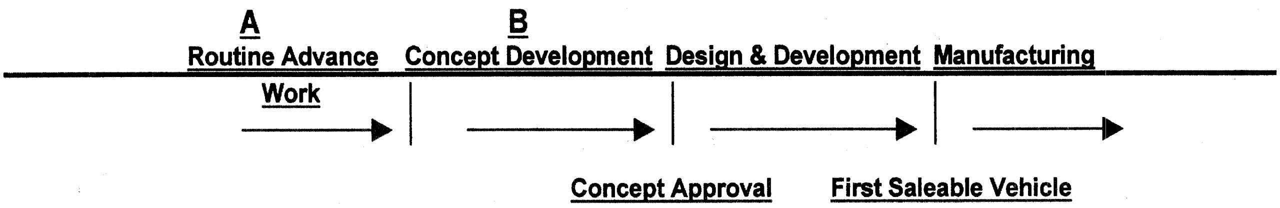
The criteria that show the most increased influence on design across all five systems are recyclability and standardized design features, parts, and subsystems, while the library of design concepts shows large increases for all the systems except chassis/suspension. Standardized designs and libraries of design concepts can support speedier and lower cost development at both manufacturers and suppliers. These design resources can also be a beginning point for developing complete modules or systems. These modules in turn can support modular vehicle configurations, while the rapid replacement and ready alteration of the modules can create opportunities for mass customization.

Though the influence of recyclability criteria will grow substantially by 2002, its ratings as a design criterion remains quite low compared with other factors in each of the five systems. This may reflect the fact that the automobile is already a highly recycled product. Managers understand the growing importance of design for recyclability, but it will still not be one of the major design criteria by 2002.

There is an important implication of the design influence patterns of recyclability and a few other criteria. Many criteria cross the scale point to move from somewhat to very influential by 2002.

This suggests that the design criteria are becoming more numerous and therefore optimizing design becomes a more complex challenge. Moreover, many of the criteria listed here, such as performance, cost, and ease of manufacture and assembly, can be quantified and hence optimized. It is therefore important for firms to adopt analytical and systematic approaches to product development rather than purely experience-based designs and suboptimal solutions. The adoption of information technology and design routines and methods, as discussed in questions 15 and 4, become even more important to address this greater complexity as the industry moves toward 2002. Design of experiments, one of many scientific approaches, and other tools can play an important role in achieving many of the different design criteria for these systems.

Different emphases between the manufacturer and supplier panels are infrequent, and largely self-explanatory. However, one disagreement is particularly interesting, or perhaps even troublesome: The manufacturers think safety is and will remain a more influential design criterion for interior design than suppliers do. Safety modules like air bags are now almost entirely developed by suppliers, as are a variety of advanced, interior, safety devices and systems. One can only hope that the difference in emphasis does not reflect a serious difference in the evaluation of safety's importance, *but that it reflects primarily* the opinion of suppliers whose interior components are less safety-related.



Q-19A. **Please indicate the percentage of employee hours expended during the preconcept approval phase of product development (the stages prior to design-and-development as indicated on the diagram above) for each of the *stylist's* design tools listed, currently and for the year 2002. Please respond for "new design" as well as for "redesign." Be sure that your answers total 100 percent.**

> **Concept approval:** Approval by corporate management to take the vehicle to volume production, including the commitment of money and human resources. This approval follows demonstration of a model of the vehicle, a demonstration vehicle, and a verification of manufacturability and financial viability of the program.
>
> **Stylist:** One who defines and develops the appearance of the exterior and interior of the vehicle.
>
> New Design: Design activity related to design of totally new platforms or new models.
>
> Redesign: Design activity related to modification of existing platforms/models.

Stylist's Tools	Median Response				Interquartile Range			
	Current		2002		Current		2002	
	New Design	Redesign	New Design	Redesign	New Design	Redesign	New Design	Redesign
3D clay mockups	28%	16%	10%	6%	25/30%	12/25%	7/20%	2/10%
Computer-based drawing tools	50	60	65	70	40/55	55/70	58/75	61/81
Manual drawing	10	6	0	0	5/11	2/10	0/5	0/5
Sketching	10	10	5	5	10/15	5/11	0/10	0/10
Virtual reality	0	0	10	5	0/4	0/5	5/18	5/15

Selected edited comments

- Three-dimensional clay will virtually disappear by early in the next decade, cost of implementing new technologies could be the only barrier.
- Although we are led to believe a car company produces vehicles purely in the virtual world, the reality is that many appearance verification properties mysteriously appear.
- Clays will still be used, but only for verification.
- Demographics (age) of managers influence this. The "experienced" workforce is most comfortable with physical properties. "Gen X" people are more than ready for visualization of math data. The two groups are sometimes unable to have meaningful conversation.

- New tools will be added to the stylist and designer tool-box. Specifics of the project and individual preference of the design and engineering teams will drive which are deployed and how.
- The more complex the product, the higher the usage of computer tools.
- Virtual reality as it develops will change the way vehicles are developed in studio and will reduce vehicle development time.
- We are not invited to participate until after the concept has been approved and is in the component sourcing stage. This is one of our perceived problems with the current process.

Discussion

Panelists forecast that computer–based drawing tools will capture an increasing share of stylists' tool-use time in the next five years, while manual drawing and sketching will recede sharply. Virtual reality will be added to the stylist's kit, and clay mockups will be less frequently utilized.

Manufacturer/supplier comparison

There are statistically significant differences in the responses of manufacturers and suppliers for the items shown in the following chart. Manufacturers indicate a greater use of 3D clay mockups for both new designs and redesigns relative to suppliers. Manufacturers also report a greater current use of virtual reality for both types of designs, and expect much higher use in five years than do the suppliers.

	Manufacturer Mean (median)	**Supplier Mean (median)**	**Significance**
	Current Year	**Current Year**	
3D clay mockups (new design)	32% (30%)	24%(25.5%)	.021
Virtual reality (new design)	4%(1%)	1%(0%)	.007
3D clay mockups (redesign)	24%(20%)	15%(15%)	.006
Virtual reality (redesign)	4%(0%)	1%(0%)	.020
	2002	**2002**	
Virtual reality (new design)	17%(15%)	8%(10%)	.005
Manual drawing (redesign)	2%(0%)	4%(1%)	.070
Virtual reality (redesign)	15%(10%)	8%(10%)	.023

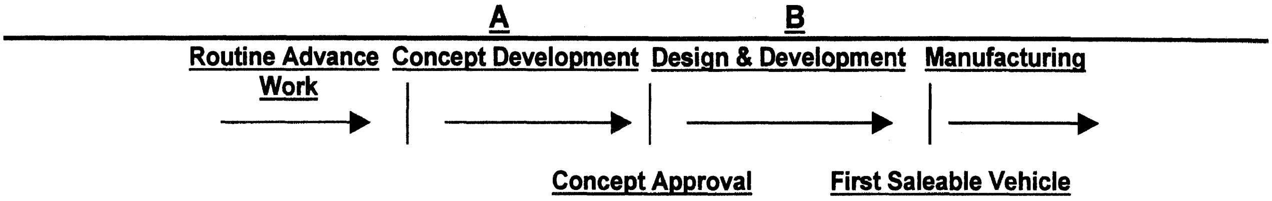
Strategic considerations

The growing reliance on computer-based drawing tools in the future will require that manufacturers and suppliers develop and retain a skilled workforce. The competition for personnel in this area is likely to intensify. New and improved software is likely to improve styling efficiency, but it will also increase the requirements for user training, as that software becomes more complex and sophisticated.

Panelists expect virtual reality to increase somewhat by 2002. The use of this technology may accelerate as management becomes more familiar with its underlying concepts and value.

Panelists expect that 3D clay mock-ups will still be used in 2002, but in a very limited way. Their use is likely to continue to decline as confidence in simulations like virtual reality grows.

The reader should keep in mind that these estimates are based on median responses. Some companies could be far more advanced in the use of these tools. Here, as is often the case, companies need to be aware of "break-out" organizations, those that move far ahead of the pack, setting and driving the new paradigms.



Q-19B. **Please indicate the percentage of employee hours expended during the preconcept approval phase of product development (the stages prior to design-and-development as indicated on the diagram above) for each of the *engineer's* design tools listed, currently and for the year 2002. Please respond for "new design" as well as for "redesign." Be sure that your answers total 100 percent.**

> **Concept approval:** Approval by corporate management to take the vehicle to volume production, including the commitment of money and human resources. This approval follows demonstration of a model of the vehicle, a demonstration vehicle, and a verification of manufacturability and financial viability of the program.
>
> New design: Design activity related to design of totally new platforms or new models.
>
> Redesign: Design activity related to modification of existing platforms or models.

Engineer's Tools	Median Response				Interquartile Range			
	Current		2002		Current		2002	
	New Design	Redesign	New Design	Redesign	New Design	Redesign	New Design	Redesign
Benchmarking	10%	10%	10%	10%	10/20%	5/15%	10/15%	5/10%
CAE tools (FEM, simulation, etc.)	30	30	30	30	20/40	20/45	20/38	21/40
Cost-function analysis	15	15	10	10	10/20	10/20	10/15	10/16
AI/expert systems/neural nets	0	0	5	2	0/0	0/0	0/5	0/9
In-house engineering databases	20	20	15	18	10/25	10/25	10/20	10/20
Quality function deployment	5	5	5	5	5/10	5/10	5/10	3/10
Rapid-prototyping tools	10	10	10	10	5/15	9/15	5/10	10/15
Virtual reality	0	0	5	5	0/0	0/0	0/10	0/10

Other responses:

- Manual methods: current 80% (new design, redesign); 2002, 20% (new design, redesign)

Selected edited comments

- AI has the potential to change how designs are arrived at.
- Good engineers should know better than to use virtual reality. Neural networks will be unavoidable.
- It's interesting to note that you did not include a category for actual "design" work such as making layouts and drawings. However, in the Asian and European concept of the role of a

design engineer, approximately half of the time is spent doing actual design work on a CAD workstation. I do not see this tool's usefulness being eliminated in the next five years. I expect that as CAE tools improve, a larger percentage of an engineer's time will be spent doing this type of work. However, the fundamental role of an engineer is to design and propose best methods to package and make components and CAD will remain the primary tool for this activity.

- More emphasis is being placed on formability simulation prior to starting mass production tooling.
- Not much time redistribution, but CAE effectiveness will be improved.
- There are still too many hidden agendas between these groups, i.e., purchasing may want a design that favors a certain vendor.
- We are not invited to participate until after the concept has been approved and is in the component-sourcing stage. This is one of our perceived problems with the current process.

Discussion

Panelists indicate that CAE tools account for the largest current share of the time engineers use design tools, for both new designs and redesigns, and that will remain flat through 2002. The time spent on other engineer design tools is also generally forecasted to change little by 2002. They expect some minor decrease in the share of time on cost-function analysis and engineering databases, and some initial use of AI tools and virtual reality in the design process by 2002.

Manufacturer/supplier comparison

There are statistically significant differences in the responses of manufacturers and suppliers for the items shown in the following chart. Manufacturers indicate a greater share of time on rapid prototyping for current redesigns, and expect proportionately more engineering time on virtual reality for both types of designs by 2002.

	Manufacturer Mean	**Supplier Mean**	**Significance**
	Current Year	**Current Year**	
Rapid prototyping (redesign)	14%	8%	.022
	2002	**2002**	
Virtual reality (new design)	8%	3%	.000
Virtual reality (redesign)	7%	3%	.009

Strategic considerations

Our panelists forecast that a relatively small portion of time spent on engineers' design tools will involve use of artificial intelligence and virtual reality even by 2002. It is difficult to predict the adoption curve for new technologies, and the reader should keep that in mind. It is likely that as these tools are introduced, uses for them will be developed that are not known today. If that happens, then their share of time spent on engineers' design tools may increase substantially.

A comment by one panelist relative to CAE merits our own comment. The panelist comment states that he/she does not expect the time devoted to CAE to change, but does expect that its effectiveness will increase. We would stress that even if the time does not change, effectiveness will likely still increase, and this will probably result from improved software and better training for CAE users.

As noted in question 19a, the forecast for the expanding use of computers in the design process will require manufacturers and suppliers to hire or develop and retain skilled personnel.

V. SUPPLIERS' ROLE IN PRODUCT DESIGN AND DEVELOPMENT DELPHI

Q-20. What percentage of product-design-and-development, in terms of employee hours expended, do you think is currently performed by each organization, and what percentage will each perform in 2002?

	Median Response		Interquartile Range	
Organization Performing Product Design	**Current**	**Year 2002**	**Current**	**Year 2002**
Vehicle manufacturer	50%	40	45/60	30/45
Suppliers (tier-one and system integrators)	28	40	20/33	30/42
Suppliers (all other tiers)	10	10	5/10	7/16
Contract house (engineering services firms)	10	10	8/10	5/15

Other responses:

- Internal: current, 55%; 2002, 45%
- Tier-two suppliers: current, 0%; 2002, 15%

Selected edited comments

- "Outside" (i.e., supplier or contract house) design-and-development cost should be proportional to purchased content.
- Body-in-White design is being turned over to tier-one suppliers. Our OEM counterparts do not have any designers assigned to their department!
- Concern exists for mega-tier-one stability (amount of cash reserves) available in event of market softening.
- Future reliance on supplier integration in noncore competency will tip the scales further away from the OEM.
- How much product design moves outside will be tied to capability of outside suppliers. Current expertise does not meet requirements.
- Manufacturers will want to outsource more but have difficulty in doing so because of control, tradition, and computer capabilities.
- Many "vehicle manufacturer" designers are contract employees, not direct, but sit on-site and not at a contract house.
- Note that suppliers may use contract houses themselves.
- OEMs will concentrate on areas in which they still add value. Other systems will be outsourced and engineering services firms will expand.
- Shift is towards tier-one system suppliers.
- Suppliers will definitely take on expanded roles between now and 2002.
- Suppliers will provide increasing "system" design in both product and process areas.
- Suppliers with expertise on component manufacturability will increasingly be designing subject components; OEMs will increasingly outsource design activity for noncore competencies (e.g., interior trim) to reduce headcount.
- The trend "was" to allow the suppliers to do more work. But with the new computer power and 3D modeling, roles of suppliers may change.

- Vehicle manufacturers will keep core design in-house, supplemented with contract. Suppliers will be expected to provide engineering support and full design capability for certain components.
- Vehicle manufacturers will retain strategic or core design for systems that differentiate their product. Full service suppliers will do all other work. "Contract resources" will fit in gaps, but will not grow unless full service suppliers elect to use them versus integrated capability.

Discussion

Our panelists forecast that tier-one suppliers will be doing more product-design-and-development in the coming years—up from 28 percent to 40 percent of the total employee hours by the year 2002. This amounts to the tier-one suppliers taking on an additional 20 percent of the OEMs current design and development work, or more than 40 percent of their own currently expended hours. Tier-two suppliers and engineering service firms are expected to continue at their current levels.

Manufacturer/supplier comparison

There is a statistically significant difference in the manufacturers and supplier estimates for design and development done by vehicle manufacturers, shown below. Note that mean values are used in comparing statistically significant differences in responses. Manufacturers estimate that they do a greater portion of design and development work than suppliers indicate, both currently and in the year 2002.

	Manufacturer Mean	**Supplier Mean**	**Significance**
	Current Year	**Current Year**	
Vehicle Manufacturer	56%	50%	.069
	2002	**2002**	
Vehicle Manufacturer	45%	35%	.041

Strategic considerations

The clear trend of an increased supplier role in product-design-and-development has several important implications. These include, but are not limited to (1) system integration; (2) full design and testing capability; (3) management of the design-and-development process; (4) quality; and (5) instability.

This data is consistent with the OEMs expectation that tier-one suppliers will provide system integration capability. (Question 21) addresses supplier attributes and those responses indicate the importance of suppliers' systems-integration capabilities.) This will place an additional burden on the suppliers. Suppliers may not have the knowledge base or resources to understand fully how their system or subsystem must interface with other components of the vehicle. This may cause unforeseen frustrations for the supplier, as well as quality problems for the OEMs. Although many suppliers seem to have the necessary resources for designing the product, such as CAE capabilities, they may still lack fully integrated systems-design CAE tools, experience, and full testing facilities. Lacking these can severely impair the product-development process. Knowledge is crucial—suppliers do not yet have the experience to handle tasks that were the historic responsibility of their customers.

There are numerous factors that influence product design. Senior engineering personnel with decades of experience and insight add great value to product design that cannot yet be captured in CAE. After all, automotive design is still a mixture of art and science. While advances in engineering continue to translate more and more of the art into science, the current math-based models are not sufficiently developed, from a systems design standpoint, to dismiss the importance of the accumulated knowledge-and-design experience of current engineering personnel. It is necessary, but not sufficient for the supplier to have adequate CAE facilities and skills.

Conventional wisdom supports outsourcing for reasons of cost effectiveness, generally because of lower labor costs and more targeted expertise at the supplier level. Outsourcing may also be reasonable on the basis that OEMs should stick to their core competencies (engine, powertrain, body, styling, assembly, and system-level electronics) and rely on supplier companies to develop competencies in other areas (such as seating and brake systems). As long as OEMs retain their overall systems-integration capabilities, outsourcing subsystems and components may be a successful strategy.

In outsourcing design-and-development work, OEMs must carefully weigh the cost-reduction benefits versus the quality risks. Outsourcing may lead to lower costs, and with the advent of CAE, even further cost reductions may be realized. However, outsourcing may also raise costs by creating an additional layer of management within the OEMs for interaction with and supervision of the supplier, especially when the supplier lacks a well-disciplined product development process. The quality risk is that there may be a knowledge gap between the OEM and the supplier about the design implications for the entire vehicle of any particular decision. Since the total engineering cost of the vehicle is less than five percent, one must carefully consider any possible quality loss as well as cost-reduction benefits.

There is a major uncertainty facing the industry over the next few years. With the advent of powerful desktop computers, where it was once cost effective to hire an outside contractor, it may now be more economical to keep the projects in-house. Integration, quality, and competency will be more under the control of the OEM if the design and development are kept in-house. Furthermore, continuity and stability, both contributing to product quality, are much greater if the knowledge base resides within OEMs, unless the particular supplier is tightly integrated with the OEM.

In light of a projected 33 percent reduction in the vehicle-development time over the next 10 years (see question 3 on product-development-cycle timing), combined with many new engineers starting with little experience, systems-integration expertise will be increasingly important in product-development success. It might also spell the difference between success and failure for outsourcing engineering.

Q-21. **Based on your experience, please estimate the importance that each of the following supplier attributes and performance factors will have in improving the cost and timing of your organization's product development by 2002. Please use the scale provided, where**

Scale: 1 = Extremely important, 3 = Moderately important, and 5 = Not important

	Mean Response	
Supplier Attributes	**Effects on Cost**	**Effects on Timing**
High level of experience in the automotive field	1.8	1.6
Supplies similar product to your domestic competitor	2.4	2.1
Supplies similar product to your overseas competitor	2.7	2.3
Proximity of supplier engineering (within 200 miles)	2.6	2.3
Proximity of supplier plant (within 200 miles)	2.9	2.9

	Mean Response	
Supplier Performance Factors	**Effects on Cost**	**Effects on Timing**
CAD capabilities	2.1	1.7
Rapid prototyping capabilities	2.4	1.7
CAE capabilities	2.2	1.8
CAM capabilities	2.2	1.9
Ability to suggest new ideas	1.7	2.0
Systems integration capabilities	2.3	2.0

Other responses – supplier attributes:

- Collocated final assembly: cost effects, 1; timing effects, 1
- Innovation ability: cost effects, 1; timing effects, 1
- Subassembly capabilities: cost effects, 2; timing effects, 1

Other responses – supplier performance factors:

- Ability to implement new ideas: cost effects, 1; timing effects, 1
- Productivity/"lean" capability; world market "needs" awareness: cost effects, 1; timing effects, 1

Selected edited comments

- CAD, is essential.
- I'm not sure the actual differences between CAM/CAE will be understood.
- OEMs will come to depend on suppliers to develop complete modules or vehicle systems. The suppliers will have to be responsible for everything relating to their portion of the vehicle.
- Solid computer system (CAD, CAM, CAE) with rapid prototyping will be critically important for suppliers to remain competitive.

- Suppliers will become increasingly important in the future, as "global" needs are addressed and UAW pressures increase.
- The timing question is difficult to answer, since timing is usually controlled by equipment and tooling timing, so supplying a similar product does not shorten timing if he has the capacity to produce the new product.
- The effects of some of these attributes on cost or timing are highly dependent on the type of commodity being supplied. For example, design and tooling intensive commodities (body sheet metal) benefit highly from robust CAD/CAM/CAE capabilities.

Discussion

Panelists forecast that most of the listed supplier attributes and performance factors will be very important in improving the cost and timing of product development by 2002. Supplier plant proximity is moderately important for improving both cost and quality, while supplier engineering proximity and supplying the product to a domestic competitor moderately affect cost.

In most instances, supplier attributes and performance capabilities have more effect on the timing of product development than they do on its cost. Whether a supplier also supplies the product to a domestic competitor, the proximity of the supplier plant, and the supplier possessing system-integration capabilities do not have differing effects on cost and timing. The supplier having a high level of experience in the automotive field is the only one forecast to have more effect on cost than timing. Supplier plant proximity is the only attribute or performance factor that is forecast to have less than a very important effect on timing. All performance factors and two supplier attributes are forecast to have at least a very important effect on cost.

Manufacturer/supplier comparison

There are a number of statistically significant differences between manufacturer and supplier estimates for the attributes and performance factors shown in the following chart.

	Manufacturer mean	Supplier mean	Significance
	Effects on Cost		
Proximity of supplier plant	3.2	2.7	.029
	Effects on Timing		
Proximity of supplier plant	3.3	2.6	.008
CAM capabilities	1.6	2.2	.009
Rapid prototyping capabilities	1.4	1.9	.041

Strategic considerations

In the previous question, panelists forecast that suppliers will have a larger role in the design-and-development process by 2002. As this supplier role increases, supplier capabilities and attributes become increasingly important. Indeed, the panelists forecast that most of these supplier attributes and capabilities will have important effects on timing and cost of their own organization's product-development activities. Experience in the automotive field will be very important for both timing and cost, while the ability to innovate will be especially important for cost, and CAD/CAM/CAE and rapid-prototyping capabilities will be very important for improving timing.

As suppliers take on a larger role in the design-and-development process, their costs will increase in many areas, including computer capability, rapid prototyping, and travel. The use of rapid prototyping by suppliers may add cost in the short term, but is likely to become the price of entry for suppliers. As manufacturers continue the push for reduced timing, suppliers must adopt tools and techniques that will make reduced timing possible.

Suppliers face a significant challenge in improving technical capabilities, as well as maintaining a stable workforce. The suppliers that best meet this challenge will be at a competitive advantage by 2002. It merits mention that suppliers see value in CAM and rapid-prototyping capability in reducing timing, but less so than do the manufacturers. Suppliers also see more value to plant proximity for both cost and timing than do the OEMs.

VI. GLOBALIZATION ISSUES

Q-22. Consider globalization of the automotive industry. How much difficulty do the following issues create for the design-and-development process for your organization currently, and how much difficulty do you expect by 2002 and 2007?

Scale: 1 = Great difficulty, 3 = Moderately difficulty, and 5 = No difficulty

External Factors Affecting Product-design-and-development Process	Mean Response Evaluation		
	Current Year	2002	2007
Protection of intellectual property	2.9	2.9	2.9
Cultural differences	2.4	2.9	3.4
Language differences	2.5	3.0	3.4
Integration of voice of the customer	2.8	3.2	3.5
Technology transfer	2.7	3.2	3.5
Transfer of engineering data and drawings	3.0	3.8	4.3

Other responses:

- Agreement on common design parameters or platforms: current, 2; 2002, 1; 2007, 1
- Time differences: current 1; 2002, 2; 2007, 3

Selected edited comments

- Cultural differences are more pervasive than language differences, which are lessening over time.
- Finding capable suppliers in other areas of the world is difficult.
- Globalization is tough! World customer needs differ dramatically and are hard to determine.
- Many OEMs are attempting (again), to develop a common platform across world markets.
- The above factors assume the development of vehicles and systems for use in multiple worldwide markets.
- The current focus is domestic and Western Europe. This will become more extensive by 2002; the difference in 2007 will be increasing interaction with Asian countries.
- The protection of intellectual property is expensive.

Discussion

In the context of increased globalization, companies are currently facing more than moderate levels of difficulty due to cultural and language differences as they try to establish themselves in other markets. Asian and South American countries, in particular, present serious challenges. The forecast over the next five to ten years indicates major improvements in all of these areas except one as companies move up the globalization learning curve. The exception is the protection of intellectual property rights, which is expected to remain fairly stable over the ten years. Most respondents seem to think that their organizations will learn to cope with these issues in the coming years. The transfer of engineering data, a technical issue rather than a social one, seems to pose less of a challenge currently, and it is expected to show substantially less difficulty in the future.

Manufacturer/supplier comparison

Manufacturers indicate slightly greater current difficulty than do suppliers in integrating the voice of the customer in the global market.

	Manufacturer Mean Current Year	Supplier Mean Current Year	Significance
Integration of voice of the customer into the product	2.4	3.0	.033

Q-22a. Consider globalization of the automotive industry. How much difficulty do the following issues create for the design-and-development process for the auto industry currently, and how much difficulty do you expect by 2002 and 2007

Scale: 1 = Great difficulty, 3 = Moderately difficulty, and 5 = No difficulty

	Mean Response		
External Factors Affecting Product-design-and-development Process	**Evaluation**		
	Current Year	**2002**	**2007**
Protection of intellectual property	2.5	2.7	2.9
Cultural differences	2.2	2.7	3.2
Language differences	2.6	2.9	3.5
Integration of voice of the customer	2.7	3.2	3.5
Technology transfer	2.6	3.1	3.5
Transfer of engineering data and drawings	2.9	3.7	4.3

Selected edited comments

- Culture differences will go away slowly.
- Even in today's world, language is a problem at times – not even global. Interface with people whose name you can't pronounce or understand when spoken is becoming commonplace.
- Movement is towards free information exchange.
- The customers' voice isn't 100 percent accurate because they often don't know what they want until they see it.

Discussion

There are few differences in our panelist's view on these issues depending on whether they apply to their own organization or to the automotive industry in general. The scores are very similar in each instance. However, the panelists seem to view their own organizations as having slightly less difficulty in handling the protection of intellectual property than does the industry as a whole, although they expect this difference to disappear over time.

Manufacturer/supplier comparison

Manufacturers indicate greater difficulty currently and in the year 2002 than do suppliers in protecting intellectual property rights in the global marketplace. On the other hand, they see less difficulty in transferring engineering data and drawings by 2007 than do suppliers.

	Manufacturer mean	Supplier mean	Significance
	Current Year	**Current Year**	
Protection of intellectual property	2.8	2.2	.038
	2002	**2002**	
Protection of intellectual property	3.1	2.5	.035
	2007	**2007**	
Transfer of engineering data and drawings	4.5	4.1	.063

Strategic considerations

The challenge of designing vehicles that appeal to potential customers across markets continues to be a major goal for all vehicle manufacturers. But the issue of cultural differences will probably become an important part of this challenge as suppliers and manufacturers expand their presence in foreign countries and encounter further differences among buyers' usage patterns and purchasing power. Both may need to hire local engineers or marketers to supplement or reorient their products for a particular market.

Although the data indicate that the protection of intellectual property will continue to pose moderate challenges, one should consider the value gained in protecting intellectual property. Given the general evolutionary nature of product design in the automotive industry, the OEMs have often been content with the natural two- or three-year advantage on a new product idea rather than vigorously pursuing worldwide patent protection. The danger that an overseas manufacturer will infringe intellectual property rights and quickly become a competitor could amplify the potential loss of sales. Certainly the benefits and costs of protecting a particular idea must be weighed against the costs of its infringement, and this calculation will often depend on the specific technology at issue.

As companies continue to enter global markets, standardization in support of mass customization plays an even more critical role. An obvious and immediate benefit of standardization is reduced costs. However, a more significant and longer-term advantage in standardization is that it will allow companies to customize a vehicle more readily, by combining (mixing and matching) various standardized functional modules. Companies that address this issue simultaneously by establishing common platforms, standardizing modules with an eye towards mass customization, and streamlining the design process are likely to win the global competition.

The panelists estimate that cultural differences create more difficulty than do language differences, at least in regard to the industry in general. In order to effectively work with a different culture, it takes much more than simple translation of one language into another. It is simply not enough to understand what the other party is saying in a different language; it is more important to understand what the party means. Otherwise any electronic translator will do the job.

When focusing on their own organizations, the manufacturers report greater current difficulty integrating the voice of the customer than do the suppliers. This may reflect the fact that OEMs have to grapple with the preferences of the end users and associated language and cultural differences more than do suppliers. In the global context, suppliers are probably already more aligned with their customers (diverse manufacturers) than are OEMs with their customers (new end users). The nature of the problem probably differs for the OEM and suppliers. The manufacturer deals with the total vehicle, which is heavily affected by market differences, while the supplier's part or component is more insulated from these market differences, and is therefore more stable.

When focusing on the industry in general, suppliers report greater current difficulty protecting their intellectual property than do manufacturers, and this difference is expected to persist in 2002. It is probably the case that suppliers are more likely to find their rights infringed, especially in the after-market, and that they have fewer resources for detecting and opposing such infringements. Both manufacturers and suppliers report little, if any, difficulty in transferring engineering data and drawings by 2007.

Q-23. **Manufacturers that design-and-develop vehicles for production in emerging markets will likely be expected to utilize local suppliers. What challenges face manufacturers in the transfer of technology to these suppliers?**

Selected edited comments

Technical capability, education and training (36 Responses)

A. Human resource issues (26)

- Developing capable, technically trained workforce. (12 responses)
- Local supplier capability and labor force (6 responses)
- Training of personnel; education level of personnel (3 responses)
- Availability of quality expatriates to guide start-up
- Cost for training
- Experience base, engineering know-how, and practiced processes
- Technical expertise/quality of processing for local suppliers
- Transferring non-technology to a transplant supplier is typically difficult. The R&D activity for these companies is typically at the mother company/country which slows down the implementation of new technology.
- **B. Technical resource issues (10)**
- Lack of technology in emerging markets (3)
- Computer systems
- Correct assessment of supplier capability by OEM
- Local suppliers' capabilities to supply the required technology
- Manufacturing processes of emerging market countries
- High-volume producer capability
- Inadequate local infrastructure, service, and resources to keep plants properly maintained and running at optimum efficiency using new technology
- Validation of vehicle with similar but not identical supplied systems

Language and culture, communications (19 responses)

- Cultural and language barriers – "way of doing business" (15 responses)
- Communications (3 responses)
- Third language: Japanese transplant in Brazil getting engineering support from USA

Quality (11 responses)

Protection of intellectual property (10 responses)

- Protection of intellectual property, in product and know-how (5 responses)
- Joint-venture agreements (2 responses)

- Loss of competitive advantage
- Ability of local suppliers to maintain confidentiality because of the movement between companies of trained/educated workers
- Transferring proprietary information.

Government regulations and political climate (7 responses)

- Cooperation with government agencies and laws
- High tarrifs and taxes in emerging-market countries
- Local customs
- Local government regulations
- Local legislative/governmental intervention

Materials (5 responses)

Design issues (4 responses)

- Design of the product to meet cost and affordability issues
- OEMs developing a common platform across world markets; agreement on common design parameters and platforms
- New-product-cost decisions with respect to design
- Revalidation for existing or new designs

Manufacturing processes (4 responses)

Miscellaneous (20 responses)

- Assumptions regarding infrastructure, utilities, and labor
- Capitalization by just 1 OEM
- Customer expectations
- Expectations
- High risk to investment up front
- Human resource logistics (travel, relocation, etc.)
- Identifying the "right" suppliers.
- Inventory management
- Investment available
- Maintaining product cost
- None as long as local suppliers are partners or subsidiaries of tier-one global suppliers
- Not any different than the joint ventures we do today. We sign confidentiality agreements and get on with business. The issue will be if dishonest governments come in and take over operations, kick out the mother company and then compete on a worldwide basis with using our

technology and investment, but that is the risk we take doing business with the likes of China, etc.

- Tier-one suppliers following OEMS into emerging markets
- Often suppliers in emerging markets with greater leverage over customers
- Personal safety
- Standard-of-living differences
- Supplier networks
- Support infrastrusture for equipment, material, etc.
- Systems
- Transferring the vehicle manufacturer's actual expectations for everything; quality expectations, data transfer, "when I (manufacturing) do this, you (supplier) should do that"; everything will be tough.

Discussion

Panelists identified numerous challenges facing manufacturers in the transfer of technology to local suppliers in emerging markets. Responses have been coded, and the categories and counts are displayed in the following table.

Category	Percent of responses (n=116)
Technical capability, education & training	31%
Language & culture, communications	16
Quality	9
Protection of intellectual property	9
Materials	4
Government regulations	4
Manufacturing processes	3
Design issues	3
Miscellaneous	17

Manufacturer/supplier comparison

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

Strategic considerations

As the industry globalizes, manufacturers will face enormous pressures to localize assembly activities, and to make use of local suppliers. Most governments simply feel that trading market access for local activity is proper. But localizing supply almost inevitably faces problems transferring technology to that local base, and that process, in turn, faces many of its own challenges.

Panelists most often express concern about the availability of appropriate technology in the local market, as well as the supply of adequately trained technical workers to use any technology transferred. These issues primarily reflect the problem of assuring equivalent production, thought to be more likely with identical technology, and disappointing experience with trying to operate such equipment with less qualified workers. A few comments note that the "obvious" solution of expatriate workers is also not as simple as it might seem.

The second most-mentioned problem is overcoming the language and culture barriers, including recognizing and coping with the local business culture and standard ways of doing business in various national and cultural regions. Question 22, also notes the importance of language and culture issues in globalization.

Two other concerns are especially frequent in the panelists' thinking. Maintaining quality standards in the face of market, capability, and attitudinal variability is difficult. Most automotive companies in North America, both manufacturers and suppliers, are committed to meeting world-class quality standards, partially for market reasons and partially for efficiency and sourcing flexibility goals. To step back to a tolerance of lower standards is simply not acceptable, and the concern is that local production in some markets may be tantamount to such a retreat. Finally, they see an issue of protecting intellectual property rights, both formally and informally, as discussed in question 22.

Manufacturers that produce vehicles in emerging markets face many challenges. These challenges, however, must be balanced against the large potential sales in these regions. The manufacturers that address these challenges most effectively will be in a position to profit from the large sales potential of these markets.

V. HUMAN RESOURCES AND TRAINING

Q-24. Consider the preparation of current engineering graduates relative to the entry-level needs of your organization in product-design-and-development. Please provide your view regarding the degree of emphasis placed by academic institutions in each skill area below, where

Scale: 1 = Too little emphasis, 3 = Emphasis just about right, and 5 = Too much empahsis

	Mean Response
Skill Areas	**Degree of Emphasis**
Mathematical and analytical skills	3.0
Computer skills (finite elements analysis, CAD etc.)	2.7
Knowledge of industrial engineering methods	2.6
Knowledge of both mechanical and electronic systems	2.5
Knowledge of business practices (marketing, accounting, etc.)	2.4
Knowledge of various manufacturing processes	2.0
Physical reasoning and synthesis (systems) skills	2.0
Hands-on design experience	1.9

Other responses:

- Communication skills/teamwork: 1
- Communication skills: 3
- Interpersonal skills: 2
- Professionalism and workplace discipline: 1
- Technical writing skills: 1

Selected edited comments

- Hands-on design experience varies widely from one school to another. We find the best, most focused, entry-level engineers have some good extracurricular project experience such as formula SAE, mini-Baja, or co-op experience. While not offered by the schools, these very worthwhile experiences are available through the schools.
- Nothing beats experience! (In the real world.)
- Too much emphasis on theory and not nearly enough emphasis on hands-on experience, real-life situations, developing personal skills to work effectively in a team environment.

Manufacturer/supplier comparisons

There are no statistically significant differences between manufacturers and suppliers for these questions.

Discussion

Panelists estimate that the preparation in mathematical and analytical skills is just about right, but that there is too little emphasis on the remaining skill areas. Hands-on design experience, knowledge of manufacturing processes, and physical reasoning and synthesis skills are especially under emphasized. That responses do not indicate "too much emphasis" on any of the analytical skills, suggesting a relative lack of practical experience in relation to them.

Strategic considerations

Physical reasoning and hands-on design experience are important for solving real-world, open-ended problems, but receive too little emphasis in the engineering students' academic training. A good understanding of various manufacturing processes is also critical for actual engineering in the automotive world, and it too receives less emphasis than it should in preparing the entry-level graduate engineer. The extent to which schools provide students with such practical experience in the curriculum varies, but extracurricular project experiences such as future car, solar-car, SAE, mini-Baja, etc. can offer the kind of hands-on experiences and knowledge that employers generally seek.

However, the engineering curriculum is sufficiently intense that many students are reluctant to engage in such extracurricular activity, especially since its absence from the curriculum suggests that it may be viewed as less important by the faculty. It is critical that engineering education institutions provide a balanced treatment of fundamental principles, physical reasoning, and engineering practice. It is a great challenge to provide the needed breadth within a four-year curriculum. A vast majority of students (about 85 percent) currently take about four and three-quarter years to complete a planned four-year degree program in engineering.

It is important that the industry recognize that, given the time constraints, the educational institutions place higher priority on engineering fundamentals, leaving some of the more practical and general skills to be learned on-the-job. These skills include foreign languages, communication skills, interpersonal skills, teamwork, marketing, accounting, etc. Most schools are attempting to provide some hands-on design experience with real-world design problems through senior-level capstone design courses, as opposed to contrived, end-of-the-chapter, illustrative problems of.

Some schools are beginning to integrate design issues and principles throughout the curriculum to hone physical reasoning and synthesis skills. Summer-internship programs and co-op programs can bridge the gap between theory and practice, provided industry exposes the students to challenging opportunities. It is important that employers not only encourage such programs but also provide stimulating environments and learning experiences for participating interns. Such an investment can pay off in countless ways for a company for many years, not least in making it an employer of choice.

Q-25. **Please check the box that represents the educational level that best matches your needs for entry-level product-design-and-development engineers currently, and in the next 10 years.**

	Frequency Selected		
	Which is most desireable (select one)?		
Educational Focus	**Bachelors**	**Masters**	**Doctorate**
Technical			
Today	77%	23%	0%
2007	44	56	2
Managerial			
Today	59	41	0
2007	23	69	8
Dual Major/Concentration (Technical and Managerial)			
Today	48	51	2
2007	20	70	10

Other responses:

- Crossover (mechanical and electrical): master's

Selected edited comments

Advanced degrees:

- Advanced degrees have more impact when earned after gaining a few years of on-the-job experience. MS, PhD degrees are not very "usable" in product-design-and-development. They are best for research-related functions.
- Advanced degrees tend to generate specialized knowledge, which can be good, but can also limit flexibility (which entry-level people typically need to be most effective).
- Management schools like Harvard have got the engineering community in a tailspin. You can't manage a car into production! Common sense is eradicated when the candidate has his lobotomy for the MBA degree.
- PhD is too specialized.
- PhDs are generally not happy or "productive" in a large company.
- There is too much emphasis on technical degrees with no corresponding contribution to the bottom line.

Internal training:

- A Bachelor's degree is required today for hiring. Our company does not generally offer college graduates product-design positions. This happens after gaining experience in labs, VSSA, testing.
- On-the-job training is the best method for training new hires. They must learn company methods to be effective.
- The majority of our design experience and development style is taught internally. We seek graduates with automotive hands-on experience (mini-Baha, co-op, etc.) and sound technical background.

- Typically, we have an entry-level engineer and send him to get an MBA if it is appropriate during his career.
- We develop managers from within the company, so a master's degree is not required. A degree does not teach people skills.
- We take our technical people and make them managers. We do not hire managerial people specifically.

Miscellaneous

- The best combination might be a bachelor's in a technical field with MBAs *if* business program includes entrepreneurial experience.
- Experience and attitude play more of a role than sheer book knowledge.
- In the vast majority of cases, even engineers with bachelor's degrees are not challenged technically.
- More co-op programs.
- Strong communication skills, creative thinking. Facilitator skills are extremely important and are most times independent of education and very dependent on the particular individual's motivation to achieve.

Discussion

Panelists estimate that most technical and managerial entry-level positions are currently best filled by graduates with a bachelor's degree, but that this will change by 2007, when they report a master's degree will best meet the needs of over half of these positions. Panelists report that a bachelor's or master's degree meets the needs of dual career entry-level product-design-and-development engineers about equally, but by 2007, most positions will require a master's degree.

Panelists' comments reveal two interesting themes. Several panelists suggest that there is little practical value to hiring PhDs for these entry-level jobs, while an equal number stress the importance of internal training in developing the people and skills required.

Manufacturer/supplier comparison

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

	Manufacturer Mean	Supplier Mean	Significance
	Bachelors	**Bachelors**	
Technical (Today)	66%	86%	.051
Managerial (Today)	37	75	.002
	Masters	**Masters**	
Technical (Today)	34%	14%	.051
Managerial (Today)	63	25	.002

Strategic considerations

Panelists expect the degree requirements to best fill positions to increase over the next decade. This is not surprising, in view of the increased breadth and depth of technical sophistication required to carry out entry-level jobs in the future. However, this trend may run somewhat counter to the sentiments of many in the industry, expressed by one panelist who observed that "even engineers with bachelors degrees are not challenged technically and by others who seem to dispute the value of formal education. One of the panelists negotiates this dilemma by suggesting that advanced degrees will add value only if they are earned after a few years of on-the-job experience! This way the employee/student can tailor his/her advanced education to those subjects that more directly add value to the engineering practice.

A bachelor's degree in engineering with an advanced degree in management after a few years of practical experience seems to be a well accepted industry practice, and some comments suggest this may continue to be so over the next ten years. The same skepticism that exists in regard to technical training exists about formal education in management, and there seems to be greater acceptance for managers who combine internal job experience and formal education. People skills, communication, and proper attitude are important, while doctoral degrees, technical or managerial, in particular do not seem to be well suited for product-design-and-development functions.

If the technical expertise that is most relevant to company needs is so likely to come from experience rather than through formal education, the motivation and incentives for obtaining advanced technical degrees seem to be debatable in most cases. There does not seem to be a career track for personnel with advanced technical degrees, except in shrinking R&D departments, whereas lucrative career tracks exist for people with advanced management degrees. This can create a problem by steering too many people away from the technical track, thus shrinking the talent pool for advanced and senior technical positions. While many companies talk about dual-track for technical and managerial personnel, most fail to establish the reward structures that will make it a reality.

Supplier panelists estimate that proportionately more of their technical and managerial entry-level positions can be best filled today by engineers with bachelor's degrees than do the manufacturers, who estimate they require more master's degree holders than do suppliers. However, this difference disappears for 2007, probably reflecting the more even distribution of technical and managerial responsibility between suppliers and manufacturers that will accompany the continued development of system integrators among first-tier suppliers.

Q-26. Please provide, for each of the technical and managerial subject areas listed below, your opinion regarding the likelihood that training and retraining of employees (engineers and management/supervisors) would improve productivity. Please use a scale of 1 to 5, where

Scale: 1 = Substantially improve productivity, 3 = Moderately improve productivity, and 5 = No effect

Technical and Managerial Subject Areas	Likelihood of Productivitiy Improvement	
A. Product-Design-and-Development	**Engineers**	**Management/ Supervisors**
Design aids and methods (DFM, DFA, FEMA, Design of experiments, etc.)	2.1	3.1
Design-and-development tools (FEM, CAD, rapid prototyping, virtual reality, etc.)	1.9	3.1
Latest technological developments	2.3	2.6
B. Personal Development	**Engineers**	**Management/ Supervisors**
Communication skills	1.9	1.6
Interactive skills	2.0	1.7
Organization skills	2.2	1.8
C. Management Tools	**Engineers**	**Management/ Supervisors**
Process improvement methodologies	2.2	2.0

Other responses – product design-and-development:

- Optimization techniques: 1 (engineers, management/supervisors)

Other responses – personal development:

- Coaching/leadership: engineers, 3; management/supervisors, 2
- Interdisciplinary: engineers, 2; management/supervisors, 1
- Time management: 2 (engineers, management/supervisors)

Selected edited comments

- It is essential that management rise through the ranks (i.e., engineering). Too many managers are "career-pathed" through critical engineering positions with no knowledge of the product, process, or people!
- Success or failure of engineers has more to do with "soft" skills (communications, interactive, organization, etc.) than technical skills.

Discussion

Panelists estimate that training and retraining of engineers in each of the seven listed subject areas will likely boost productivity quite a bit. They estimate that training and retraining of management/supervisors in product-design-and-development will boost productivity less than it would for engineers, but that training in personal development will have more effect on managers' productivity levels than it would on engineers' levels. Process improvement methodologies will enhance the productivity of both groups quite a bit.

Manufacturer/supplier comparison

There are statistically significant differences in the responses of manufacturers and suppliers for the item shown in the following chart.

	Manufacturer Mean Management/ Supervisors	Supplier Mean Management/ Supervisors	Significance
Design aids/methods (DFM, DFA, FEMA, design experiments, etc.)	3.5	2.8	.013

Strategic considerations

It is not surprising that training in design tools such as FEM and rapid prototyping are expected to have greater impact on the technical workforce's productivity than on the managerial workforce's. However, it is important to note that these panelists estimate that managerial personnel can reap moderate productivity gains from learning the latest technical developments. On the other hand, soft skills such as communication, human interaction, and organizational skills can improve the productivity not only of managerial employees but also of technical employees.

It is very important that upper management facilitates and provides incentives for continuing education and training of employees. The panelist responses to this question serve as a useful reminder that such training should be broad and cross the traditional disciplinary and functional boundaries. In fact, training can stimulate connectivity across organizational boundaries, especially if it brings employees from different parts of the organization together. Such training might include technological developments, communication skills, management tools, and product-design methods, and these could usefully be addressed to both the technical and managerial communities. This is one of the keys to improving productivity of technical and managerial staffs. Many societies such as SAE, ASME, IEEE as well as universities offer short courses and one-day seminars on all these subjects to help employees "sharpen the saw."

The supplier panelists expect higher productivity gains than do the manufacturers from training managers in technical design aids and methods. This may reflect the relatively more recent assumption of expanded responsibility by the major suppliers, leaving their managers a bit behind the manufacturers in relevant technical experience.

Q-27. Please evaluate the expected need of each of the following skills over the next 10 years. Please circle your answer, where

Scale: 1 = Extremely important, 3 = Moderately important, and 5 = Not important

Also, for each skill please provide an indication of the most appropriate training site, where

Scale: 1 = Principally a formal unviersity program, 3 = 50% formal university and 50% in-house training, and 5 = Principally in-house training

	Mean Response	
Skills	**Expected Need**	**Training Site**
General		
Foreign languages	2.7	2.1
Creative thinking	1.8	2.9
Communication	1.6	3.6
Systems perspective	1.9	3.6
Team work	1.7	3.9
Design for Specific Areas		
Environment	2.8	3.1
Reliability and safety	2.0	3.2
Design standards (UL, ASME)	2.9	3.4
Performance	2.1	3.5
Assembly	2.2	3.8
Manufacture	2.1	3.8
Commonality	2.4	3.9
Technical Skills Areas		
Software engineering	2.9	2.1
Finite element modeling and analysis	2.1	2.4
Mechatronics (mechanisms and controls)	2.5	2.4
Application of statistics in design	2.4	2.6
Robotics	3.1	2.6
Cost accounting	2.9	2.7
Materials selection	2.3	2.8
Sketching/drawing	3.0	2.8
Ergonomics	2.7	2.9
Statistical process control	2.5	2.9
Project data management	2.3	3.0
Project management tools	2.3	3.0
Internet	2.5	3.1
CAD systems (MCAD, ECAD etc.)	2.0	3.2
Geometric tolerancing	2.3	3.3
Manufacturing processes	2.0	3.5
Benchmarking	2.4	3.8

Other responses:

- Cost estimating and analysis: need, 2; site, 5

Discussion

The panelists rate four of the five general skills as quite important: communication, team work, creative thinking, and systems perspective. They report that both formal university and in-house training are appropriate for creative thinking, but that weighting the mix towards in-house training is more appropriate for the other three skills.

The panelists rate five of the seven specific design skills as quite important, although perhaps not quite as important as the four general skills discussed above. The only two that fall in the moderately important range are design standards and design for the environment. Panelists view these 2 skills, along with design for reliability and safety, as most appropriately provided through both formal university and in-house training; the mix for the other four shifts towards more reliance on in-house efforts.

The panelists rate 12 of the 17 technical skills as quite important, and the remaining 5 as moderately important. The 3 technical skills with the highest ratings are CAD systems, finite element modeling and analysis (FEMA), and manufacturing processes. The appropriate training sites for these skills are mixed, weighted to university, and weighted to in-house, respectively.

Respondents identified the most appropriate training site for 7 of the 8 most important skills as weighted towards in-housing training. They tilt towards university training for FEMA, the other most important skill. Panelists see only 4 of the 29 skill areas as better suited by a training mix tilting towards the university: FEMA, foreign languages, mechatronics, and software engineering.

Manufacturer/supplier comparison

There are statistically significant differences in the manufacturer and supplier responses for the items in the following table.

	Manufacturer Mean	**Supplier Mean**	**Significance**
	Expected Need	**Expected Need**	
Foreign languages	2.9	2.6	.065
Commonality	2.1	2.6	.007
Performance	1.8	2.3	.030
Reliability and safety	1.7	2.3	.012
	Training Site	**Training Site**	
Creative thinking	3.2	2.7	.067
Commonality	4.3	3.6	.015
Reliability and safety	3.5	2.9	.048
Application of statistics in design	3.0	2.2	.010
CAD systems (MCAD, ECAD, etc.)	3.7	2.8	.005

Strategic considerations

It merits comment that our panelists rate all 29 of these skills areas as becoming at least moderately important over the next decade. This might mean that the challenges and issues confronting the industry are indeed massive and complex, or it might mean that the industry is paying insufficient attention to prioritizing its needs. It certainly is important that any single company develop a clear sense of the immediacy and scale of the challenges it confronts. In terms of this kind of question, some skills must necessarily fall to the comparatively less important side of the scale within a particular company.

Formal education in universities provides basic understanding of the engineering fundamentals and principles. Most skills that are critical to employee performance tend to be product or process-specific and are not usually taught in schools, at least to the level of specificity that automotive manufacturers and suppliers require. The somewhat negative views of university preparation for entry-level engineering positions, expressed in responses to question 24 (Preparation of engineering graduates for your organization in product design and development) are consistent with, if not approving of, this situation. These circumstances probably account for the panelists' general emphasis on mixed training, usually with a tilt towards in-house training.

Manufacturers report somewhat less need for foreign language training over the next decade than suppliers do. This probably reflects their higher levels of global experience than that of the general supply base. On the other hand, we would expect that somewhat lower supplier emphasis on design for commonality, reliability and safety, and performance areas would diminish as the larger suppliers take on more responsibility for more complex and larger systems of the vehicle. Manufacturers, compared to suppliers, also report that a training regime tilted more towards in-house efforts is more appropriate for five different skill areas. This undoubtedly reflects the manufacturers greater resources, as well as the economies of in-house training across a much larger engineering workforce.

Although many skills that are critical for an industry setting can be acquired through informal, on-the-job experience, a formal training process can add substantial value in reducing learning time and costs. In order to be competitive in the future, companies should either set up in-house training facilities or link up with professional societies or universities to provide employees with much needed continuing education. Advanced degrees, whether technical or managerial, may be most useful when employees return to school after a few years of practical experience so that they can "customize" the education according to the skills needed on the job. However, short courses and one-day seminars can be very useful in keeping up more pressing and immediate skill demands.

Distance learning will probably play a more prominent role in future training, as the tools it requires, such as video technologies, the internet, etc., are in place and improving rapidly. Shared generic training across companies will probably increase, to restrain the costs of course development, materials, and instructors. Most training needs are probably generic, rather than proprietary.

Q-28. In your view, how is the product-development process in the automotive field different from other medium-to-high-volume industries such as appliances, office products, semiconductors, computers, etc.? Please note those industries in which you have experience.

Selected edited comments

Market complexity (10)

- The competition is global in nature. The automotive industry is more complex with higher risk (safety). The automotive industry is more structured; The opposite is true of the aerospace industry.
- Auto industry is very similar to others although it is larger and more complex.
- Complexity and urgency equals permanent crisis, many issues, many solutions possible, and one fast decision; uncertainty in both market and technology; weight of history (facilities, people, markets).
- I believe that the auto development process is far more complex due to the various technologies involved and the uncontrolled environment. My experience is solely auto.
- My experience is primarily in the automotive field and the level of complexity that is much higher than all other fields mentioned. The automotive industry has all the other industries included in it: computers, HVAC, semiconductors, etc.
- I only have experience in the automotive industry. However, I would make one observation. The newer the technology, the more rapid the change. The product development process (not the process timing) shouldn't be too much different between industries. The number of component parts to a system dictates the complexity and overall product development timing.
- In consumer/industry durables field, the automotive product development is more sophisticated than any but aerospace.
- The design process must remain defocused to "see" opportunities from other industries. The other industries tend to narrow their viewpoint to existing product. The great changes in those industries usually are great "surprises"!
- The other industries noted are becoming more like commodities, as far as value, cost, importance.
- The reliability requirements in a hostile environment demand a very robust and proven process. There is no room for failure in many areas of automotive design due to the safety critical nature of many of the subsystems. Tie that in with the immense competition to create high quality products, makes the job even more challenging. (At competitive prices!!) I have worked in the aerospace industry where cost was typically not an issue.

Timing issues (8)

- All of the industries mentioned; appliances, office products, semiconductors, and computers face similar challenges. Automobile development is tending to be more global especially regarding competitors. Product technology/performance does not move as fast as semiconductors. Recently read that "if automobile development was similar to computers, a Lexus would get 100 mpg on a thimble of gas and cost $100."

- In my opinion, the industries are very similar. The appliance industry tends to involve us earlier in the program than automotive industry does.
- The automotive industry is much slower than consumer products because of reliability issues and tradition. I have worked in aerospace, metals and automotive industries.
- New technology and new components change more rapidly, in the auto industry. The auto industry must plan/design for customer needs farther into the future than non-automotive industries. I have been involved with the nuclear power industry and the sand casting industry.
- I spent my entire career in the automotive industry – 35 years. We put out far less product now with the people we have. They are busy creating new systems and measurements, which take up valuable engineering time.
- New vehicle retailing trends may dictate a major decrease in product development cycle times.
- The product development process is more organized but more time is needed for design validation through rapid prototyping.
- Time constraints are much greater in the auto industry. They are less willing to take chances.

Styling concerns and customer expectations (7)

- Consumers want to personalize their vehicles. (2)
- Automotive design is driven by styling, which forces functional parts into odd shapes which makes them difficult to analyze. This forces a reliance on cut and try and prove-out of the final product with the final product. In other products, form follows function and part design is suited to analytical tool capability, thus permitting much better up front design.
- Customer expectations are very high. More features along with continuously improved quality and reliability are desired by consumers They always wants more "stuff" with fresh styling and competitive pricing.
- Emphasis on styling/visual much stronger in auto industry. (Locomotive design experience much more functionally based.) Volume of production/amount of high volume tooling and dies is much higher for auto industry.
- I believe that influencing the emotional response of the customer is more important in the automotive business. I only have experience in the automotive field.
- There is a high emotional factor in product.
- With the exception of computers, technology is advanced very rapidly and the consumer always wants more for less.

Other regulatory and safety concerns (7)

- Extremely unique safety regulations/standards require extensive testing to confirm the design.
- Fail safe products as well as product liability are concerns.
- Ground vehicles are regulated to the point where the manufacturers are almost utilities.
- I have some experience in the commercial refrigeration compressor industry and I think that it parallels the auto industry fairly closely. However, I feel that the product development process in industries such as those that you mention above are much less restricted than the auto industry in terms of technology and resources mainly due to significant differences in regulatory and customer issues relative to product reliability and product liability.
- More outside regulation is enforced at every stage.

- Safety is a primary concern.
- There is more emphasis on customer safety.

Cost for investment (5)

- I'm familiar with testing equipment, furniture, marine and food/beverage industry. Automotive tends to have the lowest profit margins or more generally, a higher emphasis on cost. Regulations (safety and emissions) seem to hit automotive more than the others, which drives cost and development time up. The recent trend is that experienced engineers are retiring, leaving green engineers to function programs; this is increasing suppliers work due to being the knowledge base and having to explain why things are being done a certain way.
- Cost, complexity and lead time for dies and fixtures as well as assembly equipment required to produce a new vehicle are distinctive aspects.
- The auto industry requires a big investment with a very high risk;
- We are concurrently developing vehicle platforms on three continents for products that will be launched on three continents. The other guy's parts may be for use in global markets, but they are typically designed in one location and manufactured in one location. Also, in most cases their product costs and capital requirements are less.
- Tooling commitment is a huge cost and end item price is high as well.

Cost for ownership (2)

- The automotive engineer has a responsibility to create products with high value for the money. This is the second largest expense for most customers (home number one). And yet, a car loses its value over time.
- The cost of ownership including maintenance, operating cost, insurance cost and of course resale value is more important than with other products.

Discussion

Panelists compared the automotive industry product-development process with other medium-to-high-volume industries such as appliances, office products, semiconductors, computers, etc. They identified a number of ways that the automotive industry differs from these others. Some focused on product development, and others focused on seemingly more general comparisons. The most important differentiating characteristics of the automobile industry include product and market complexity (10); relative timing and change (8); customer satisfaction (6); safety requirements (3) and other regulatory concerns (4); styling constraints (2); and cost, both for investment (5) and ownership (2). Other factors mentioned by more than one respondent include globalization, and fast-moving technology. Five panelists did observe that the automotive industry is similar to the other industries in which they have experience.

The product and market complexity characterizing the automotive industry permeates its activities, including its product-development efforts. Designing an expensive product with over 2,000 components that must appeal to differing tastes, serve global markets, and roll out of the factory on-time at high quality is indeed a complex challenge. Time pressures create permanent crisis; when combined with cost pressures they inhibit new innovations.

Extensive testing is required to meet extremely stringent safety requirements and other regulatory demands, such as emissions and fuel economy. This restricts not only the product, but the product-development process too as more time is required for design validation.

Perhaps more than in the comparative industries, the automobile must reflect a distinctive styling, and, as one panelist expressed it, the vehicle's functions are constrained by its form.

Investment costs are large and risky. The tooling commitment alone is huge, and market uncertainty puts this and other product investments at high risk.

Manufacturer/supplier comparison

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

Strategic considerations

The heavy emphasis on product styling is probably one of the truly different constraints on the automotive industry relative to most other durable goods industries. In most other industries, function sets the general limits for style; in the automotive industry, function sometimes must accommodate the parameters demanded by style, albeit within the basic constraint of packaging people and some of their belongings.

The panelists suggest that many of the characteristics identified as making the automotive industry distinctive or even unique are probably more matters of degree than of kind. For many in the industry, this will smack of heresy, since so many auto-industry participants have believed the industry is absolutely different from any other. For instance, the aerospace industry also has to deal with high investment and safety constraints. Most other industries also face cost and time pressures, globalization challenges, government regulations, and changing market demands.

It is important that the automotive industry be open to learning from the experiences and efforts of other industries. One of the most impenetrable barriers to such learning is to emphasize the industry's uniqueness. This can, and has, led the industry to be slow in exploiting the experience of other industries. The recent efforts of some companies to benchmark themselves against nonautomotive companies constitute an important step, and should be encouraged. The automotive industry is different, but not so different that it cannot learn from others. Its participants should make careful and precise evaluations of what the differences may mean for such lessons, rather than use the differences as grounds for ignoring such opportunities.

To stay competitive in global markets, the auto industry should continue to modularize product designs, as have the personal-computer, bicycle, and furniture industries. To be sure, an automobile is much more complex than office furniture, but a good model of modularization can help the auto industry pursue mass customization. Similarly, the industry may need a new set of verification tools to verify the performance of systems assembled from a library of proven "off-the-shelf" subsystems. Such a resource could be extremely valuable in meeting the more complex and pressing demands of the automotive market.

The automobile is certainly not a "computer on wheels." (If the automotive industry is too aware of its uniqueness, some computer enthusiasts seem to see all other industries as simply reflections of their own core product and activities!) The physical laws governing the performance of an automobile are much too complex to treat it as simply a computer on wheels. However, the design approaches and principles underlying the use of modularity can be usefully transferred between the two industries.

Finally, the automobile industry can and should learn to adopt new ideas quickly. There never seems to be enough time to invest in a new concept given the competitive constraints. A fundamental shift in the paradigm of the unique automotive industry is needed. Fortunately, a number of panelist remarks suggest this is happening, and that is a healthy trend indeed.

APPENDIX
(Panelist use)

We have reorganized the Questionnaire order for communication effectiveness. The conversion chart is shown below.

Product Development Delphi Question Reorganization		
Questionnaires	→	Final Product
Q-1		Q-6
Q-2		Q-7
Q-3		Q-5
Q-3a		Q-5a
Q-4		Q-15
Q-5		Q-8
Q-6		Q-1
Q-7		Q-9
Q-7a		Q-9a
Q-8		Q-20
Q-9		Q-21
Q-10		Q-22
Q-11		Q-23
Q-12		Q-2
Q-13		Q-3
Q-14		Q-4
Q-15		Q-10
Q-16		Q-14
Q-17		Q-16
Q-18		Q-17
Q-19		Q-18
Q-20		Q-11
Q-21		Q-13
Q-22a		Q-19a
Q-22b		Q-19b
Q-23a		Q-12a
Q-23b		Q-12b
Q-24		Q-24
Q-25		Q-25
Q-26		Q-26
Q-27		Q-27
Q-28		Omitted
Q-29		Q-28

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KEY WORDS

Acceleration/braking	12a
Aesthetics	18
Analytical skills	24
Analytical testing	14
Application of statistics in design	27
Artificial Intelligence	13, 19b
ASME	27
Assembly	27
Automatic controls	12a
Automotive experience	21
Benchmarking	19b, 27
Body	12a
Body panel	18
Business practices	24
CAD (computer aided design)	21, 13, 24, 26, 27
CAE (computer aided engineering)	20, 21, 4, 10, 14, 11, 19b
CAM	21, 13
Chassis	18, 12a
Collaborated innovations	17
Co-locating/common workspace	7
Combustion analysis	12b
Comfort	12a
Common databases	7
Common goals	11
Commonality	27
Communication	7, 8, 26, 27
Competitive pressures	1
Complexity	28
Component engineering	2, 3, 4, 19a, 19b, 12a
Computer networking	13
Computer related tools	13
Computer skills	24
Computer software	15
Computer tools	4
Computer-based drawing tools	19a
Computers	8
Concept approval	2, 3, 4, 19a, 19b
Concept development	2, 3, 4, 19a, 19b
Conceptual design	12b

Concurrent design	15
Contract house	20
Cost	21, 10, 12b, 28
Cost accounting	27
Cost of repair	18
Cost-function analysis	19b
Crash	12a
Creative thinking	27
Culture challenges	22, 22a, 23
Customer research	2, 3, 4, 19a, 19b
Customized integrated software	13
Cut and try methods	1
Data transfer	22, 22a
Databases	8, 10, 13
Design aids	26
Design approaches/strategy	15
Design changes	
Design iterations	1
Design of experiments	16, 26
Design progress measurement system	15
Design reviews	15
Design specs	2, 3, 4, 19a, 19b
Design standards	27
Design/development tools	26
Development of new features	2, 3, 4, 19a, 19b
Development of new systems	2, 3, 4, 19a, 19b
Development time	18
DFA	26
DFM	26
DFMA	11
Dies	14, 12b
Distribution	11
Domestic competitor	21
Doors	12a
Drawing	22, 22a, 19a, 27
Durability	12a,
Dynamics	12b
ECAD	27

Education	23, 11, 25
Electromechanical design	12b
Electronic systems	24
Engine	18, 12a, 12b
Engineering design	5
Engineering feasibility	2, 3, 4, 19a, 19b, 12b
Engineering personnel	14
Engineering service firms	20
Engineers	26
Environment	27
Environmental standards	9
Ergonomics	18, 27,
Europe	2, 3, 4, 19a, 19b,
Evaluation of design for manufacturability	12b
Expert system	13, 19b
Face to Face meetings	7, 15
Fatigue	12a, 12b
Fax	7
FEA	9, 10, 13, 24, 27
FEM	26
FEMA	26
Final design	18
Financial feasibility	2, 3, 4, 19a, 19b
First saleable vehicle	2, 3, 4, 19a, 19b
Fluid-flow analysis	12b
Formal process monitoring system	6
Freezing design specifications	15
Geometric tolerancing	27
Global economy	9
Global market	11
Global standards	
Global vehicle development	1
Globalization	22, 22a, 28
Government Regulations	23, 18, 28
Handling	12a
Hands-on design experience	24
Harshness	12a
Heat-transfer analysis	12b
Human Resources	11
HVAC	18, 12a

Independent inventors	17
Independent researcher companies	17
Industrial engineering methods	24
In-house engineering databases	19b
Integrated analysis of systems	12b
Integration	13, 12b
Intellectual property	22, 22a, 23
Interactive computer tools	7
Interactive skills	26
Interactive Video conferencing	
Interiors	18
Interior	12a
Internet/intranet	7, 27
Investment	28
Japan	2, 3, 4, 19a, 19b
Knowledge bases	13
Labor	9,
Language	22, 22a 23, 27
Large-screen workstations	13
Lead times	2, 3, 4, 19a, 22b
Management	6, 15, 8, 11, 26
Manufacturing/full scale production	5, 23, 2, 3, 4, 16, 18, 19a, 19b, 12b, 27, 28
Market demands	28
Market quality	9
Materials	23, 27
Math-based engineering	10, 13, 12a
Mathematical skills	24
MCAD	27
Mechanatronics	27
Mechanical systems	24
Mechanisms and controls	27
Neural network	13
New design ideas	1, 19a, 19b
New technologies	1,
Noise	12a
Not invented here	8, 1

syndrome (NIH)	
Occupant dynamics	12b
Option packages	1
Organizational barriers	8
Organizational skills	26
Other industries	28
Outsourcing	20
Overnight mail	7
Overseas competition	1, 21
Overseas manufacture	9
Packaging constraints	18
Parametric design tools	13, 12b
Performance	21, 18, 12a, 27
Personal development	26
Physical reasoning skills	24
Physical testing	14
Pilot build/test	2, 3, 4, 19a, 19b
Platforms	1, 3, 11, 28
Political climate	23
Process development/validation	2, 3, 4, 19a 19b
Process improvement technology	26
Process/organization management	4, 11, 13
Product and process innovations	17
Product development cycle duration	2, 3, 4, 19a, 19b
Product development process	6
Product liability	9
Product variations	15
Project data management	27
Project management tools	27
Prototype	2,3,4, 10, 14, 19a, 19b
Purchasing	5
Quality	23, 11
Quality function deployment	16, 19b
R&D	1
Rapid prototyping	21, 14, 16, 11, 13, 19b, 26
Recyclability	7, 16, 18
Redesign	1, 19a, 19b

Reducing weight	18
Regional/global trade pacts	9
Reliability	27
Reliability estimation tools	12b
Re-training	26
Ride	12a
Rigid and flexible body dynamic analysis	12b
Robotics	27
Robust design	15
Routine advance work	2, 3, 4, 19a, 19b
Safety	9
Safety	18, 12a, 27, 28
Sales and Marketing	5
Seating	12a
Service/repair/ maintenance	16, 18
Sharing ideas	11
Similar products	21
Simulation of manufacturing and assembly activities	13
Simultaneous development team meetings	7
Sketching	19a, 27
Software	8
Software engineering	27
Standardization	1, 4, 18
Statistical process and control	27
Statistical tools for design	13
Steering	12a
Streamlined design process	1
Stress analysis	12b
Structures	12b
Styling	5, 12a, 28
Styling/clay models	2, 3, 4, 19a, 19b
Stylist	19a
Supervisors	26
Supplier role	4
Suppliers	1, 20, 21
Suspension	18, 12a
Synthesis skills	24

System integration	21,
System synthesis	12b
Systems perspective	27
Team work	27
Technical capabilities	23
Technology transfer	22, 22a
Testing requirements	10
Time	1, 21, 10
Time pressure	28
Tire	12a
Tooling	14, 28
Tools for conceptual design	13
Training	23, 26, 27
Training site	27
Transmission/driveline	18, 12a
Tribology	12b
UL	27
United States	2, 3, 4, 19a, 19b
Universities	17, 27
Value analysis	16
Vehicle cost	18
Vehicle manufacturer	20
Vibration	12a
Video Conferencing	7
Virtual environment	7
Virtual reality	11, 13, 19a, 19b, 26
Voice mail	7
Voice of customer	22, 22a
Windows	12a

