Future Changes to the Vehicle Fleet: Effect on Highway Safety

William D. Glauz
Midwest Research Institute
Kansas City, Missouri

Following the oil crisis of 1973–1974, a revolution took place in the automobile industry. A second "energy shock" occurred in 1979–1980. As a result, the price of fuel rose sharply. The federal government established industry fuel economy standards that became progressively more stringent through 1985.

In response to these actions, U.S. automobile manufacturers downsized their vehicles—in length and width and weight. Imports, which were generally smaller, cheaper, and more fuel efficient, captured a larger share of the market. As these trends became established in the late 1970s and early 1980s, many projected a continuation of the trends and the emergence of a substantial volume of mini- and microvehicles.

During the same period, truck size and weight laws were also changed. The 1982 Surface Transportation Assistance Act (STAA) *(1)* was passed, which forbids the states from prohibiting, on designated highways, semitrailer lengths as large as 48 ft (45 ft was the previous maximum length in common use), truck widths of 102 in. (up from 96 in.), truck weights of 80,000 lb (up from 73,280 lb), and operation of truck tractor-semitrailer-trailer combinations (doubles) with trailer lengths up to 28 ft.

In light of these changes and predictions of the future, it is appropriate to ask what effects these alterations to the vehicle fleet will have on highway safety. More specifically, what effect will the changing fleet have on relationships between highway safety and roadway features, for example, lane width and horizontal and vertical curvature.

Some of these issues are addressed in this paper, which is based entirely on the literature, and do not represent any new data collection efforts. However, the literature reviewed is quite diverse, most of it is quite recent, some of it is unpublished, and much of it is "expert opinion."

The paper is organized into three major topics: (a) a review of the vehicle and highway features of potential interest; (b) a review of recent trends in, and future projections for characteristics of automobiles and trucks; and (c) an assessment of how the relationships between highway safety and roadway features may be affected by future changes to the vehicle fleet, and therefore how resurfacing, restoration, and rehabilitation (RRR) planning might be affected.

VEHICLE AND HIGHWAY FEATURES OF INTEREST

Highway safety has been examined from the viewpoint of roadway elements and vehicle characteristics in two major syntheses. These are reviewed briefly, and the 10 roadway features of interest to the RRR study are individually addressed. [The results of the RRR study are published in TRB *Special Report 214: Designing Safer Roads (2)*.]

FHWA Synthesis

A Federal Highway Administration (FHWA) synthesis *(3)* focused on the roles of traffic control and roadway elements in highway safety. The study examined 17 subject areas, one of which was roadside features, an area that has been addressed at length in the literature. Specific findings are summarized in the section in this paper titled Application of Results to RRR Projects. The other subject area for which vehicle characteristics were believed to be of importance in the FHWA synthesis was intersections—three concerns were voiced: collisions between large and small vehicles, vision limitations for drivers of small vehicles occasioned by the presence of larger vehicles, and anticipated extra driver workload caused by the need for clutching and gear shifting and confined interior space.

FHWA Contractor Study

McGee et al. recently completed a 2-year FHWA research study, *Highway Design and Operations Standards Affected by Vehicle Characteristics (4)*. A major portion of this study was a review of geometric design and traffic control criteria that are affected by vehicle characteristics, as well as an assessment of the appropriateness of relationships between those characteristics and the geometric design and traffic operations criteria. Fifteen standards or traffic operations criteria were identified that incorporated one or more vehicle characteristics. In some instances, the characteristic is included explicitly; for example, driver eye height is a parameter used in the measurement of acceptable sight distance. In other cases, the characteristic is not explicitly stated, but is implied. An example of this is the effect of vehicle width on lane width, which is not part of the written American Association of State Highway and Transportation Officials (AASHTO) policy, but is inherent in it because the policy was originally developed based on research pertaining to vehicle width.

Twelve of the 15 standards examined relate to 4 areas of interest to the RRR study: lane width, horizontal and vertical curves, sight distance, and intersections. The McGee et al. study does not mention the other six highway features of interest to RRR, although clearly based on the literature cited, most if not all of these features were also reviewed. The study findings in this regard are presumably covered by the statement, "the absence of a particular standard indicates that it was determined that a vehicle characteristic does not influence the standard."

The vehicle characteristics found to influence one or more standards are weight, length, height, width, wheelbase, underclearance, off-tracking, acceleration ability, maneuverability, side friction factors, braking ability, driver eye height, suspension, load distribution, and headlight characteristics. Several of these involve, in turn, more specific vehicle characteristics. For example, offtracking is a function of the number of units (if a combination vehicle), the wheelbase of each unit, locations of hinge points, vehicle widths, and overhangs. Braking ability encompasses the braking system, type and condition of tires, load and load distribution, and so forth.

Roadway Characteristics of Interest to the RRR Study

Each of the 10 roadway features reviewed by the Committee for the study of Geometric Design Standards for Highway Improvements is assessed as to whether they are likely to be influenced by reasonable changes in vehicle characteristics. This assessment is based largely on the preceding two major studies, supplemented by other literature on sideslopes, roadsides, and pavement edge drop-offs.

1. *Shoulder width*: No relationship between vehicle characteristics and shoulder width is apparent in the literature. If it is implied that shoulder widths should safely accommodate parked vehicles, then vehicle width would be of concern. However, because major changes in vehicle widths are not expected, this feature will not be considered further.
2. *Shoulder type*: No relationship between vehicle characteristics and shoulder type is evident in the literature other than the obvious implication that a shoulder must have the stability necessary to sustain loads imposed by the vehicles using them. On small-radius horizontal curves where the pavement width is not adequate, truck off-tracking could lead to increased shoulder usage, and hence increased shoulder damage unless it is designed to accommodate such loads. This issue is best covered by lane width and horizontal curvature considerations, however, so shoulder type will not be considered further.
3. *Lane width*: Lane width was found to be implicitly linked to vehicle width by McGee et al. *(4)*. However, the research supporting the STAA-mandated 102-in. truck width on roads with 12-ft lane widths *(1)* did not indicate safety degradations relative to the earlier 96-in. widths. On roads with less than 12-ft lanes, the safety impacts of wider trucks should be considered.
4. *Horizontal and vertical curvature*: These features are directly related to the ability of the vehicles to stop or accelerate. Thus, vehicle characteristics such as driver eye height, braking ability, length, width, and engine performance may be important. Also, as mentioned earlier, vehicle off-tracking may be a problem on small-radius horizontal curves.
5. *Sideslope*: Although the two major FHWA studies did not identify sideslope as being related to vehicle characteristics, others suggest there is a vehicle size relationship. Woods found that the likelihood of rollover for smaller vehicles is greater than that for larger vehicles *(5)*. Woods further states that the testing that led to the guideline of 3:1 unprotected sideslopes involved only large vehicles, and that therefore, a 4:1 value should be used where practical, for the benefit of smaller cars. Unfortunately, no data exist to quantify the effect of vehicle size.
6. *Roadside*: Again, although the two major FHWA studies did not address roadside issues such as guardrails, poles, and the like, their contribution to safety has been well researched. Vehicle characteristics such as weight and bumper height are very important.

7. *Sight distance*: Stopping and passing sight distances depend strongly on vehicle braking and acceleration capabilities, and to some extent on driver eye height and vehicle length.

8. *Bridge width*: Although the FHWA synthesis *(3)* examined bridge width, it did not relate it to any vehicle characteristics. An independent review of the literature on bridge width indicated that the vehicle-width relationships have not been addressed. There is some suspicion that trucks are more of a safety problem at narrow bridges than automobiles, but issues such as 102- versus 96-in.-width trucks or narrower versus wider automobiles have not been examined. Widening of bridges is usually a matter of many feet, not inches, so it is unlikely that small changes in vehicle width will be important.

9. *Pavement edge drop-off*: Pavement edge drop-off poses a problem for vehicles whose right wheels have moved off the pavement and must therefore remount the drop-off. In attempting to remount the pavement, the driver may lose control of the vehicle, causing it to cross into opposing lanes of traffic.

Graham and Glennon *(6)* provide an extensive review of the literature on this topic, as well as new simulation results. They discuss several experimental studies using a variety of automobile sizes (including minicompacts), drop-off heights, speeds, and maneuvers. The experimental studies indicated only small differences as a function of vehicle size, up to the drop-off height tested (~4 1/2 in.), so their authors tended to merge results across vehicle sizes. The simulation results also revealed that, "responses to the drop-off were nearly identical for a mid-sized and a compact automobile." They therefore recommended maximum drop-off heights based on criteria other than vehicle size.

10. *Intersections*: Although interchange design has been found to involve many vehicle characteristics such as vehicle length, deceleration, and acceleration capability, most of these are not expected to change enough to affect geometric design. The exception is the intersection return radius, which is strongly affected by vehicle off-tracking characteristics.

PRESENT AND FUTURE DISTRIBUTIONS OF VEHICLE CHARACTERISTICS

Trucks

Fewer data are compiled on vehicle characteristics of trucks than of automobiles, with the exception of weight data. And essentially no formal studies have been conducted of projected distributions of truck characteristics. However, this situation is likely to change.

The Surface Transportation Assistance Act of 1982 *(1)* made a number of changes in allowable truck specifications and mandated a number of studies, including the RRR study *(2)*. Another STAA study, the "Double Trailer Monitoring Study," was conducted by the Transportation Research Board, and the results are published in *Special Report 211: Twin Trailer Trucks (7)*. Although it focused on double trailer configurations, other truck issues were examined as well. The findings on current and projected usage, although largely based on expert opinion, are perhaps the most definitive in existence.

At present, the principal data on truck characteristics deal with truck weights and, to a lesser extent, vehicle classifications. Such data are obtained annually, on a voluntary basis, from the states by FHWA for the Annual Truck Weight Study. However, they do not represent a statistically valid sample. The Census Bureau conducts a Truck Inventory and Use survey every 5 years of truck owners of a sample of registered vehicles. The most recent survey was in 1982; the results have not yet been published.

It is likely that changes in the distributions of truck characteristics will occur. The impetus behind the changes is the STAA, which, as noted earlier, mandated that the states could not prohibit trucks with certain characteristics from the Interstate system or other designated routes. Some of these designated routes are likely to be highways of interest to the RRR process. The changes to be expected are longer (48-ft) semitrailers, wider (102 in.) trucks, heavier (80,000 lb) trucks, and doubles replacing a portion of the tractor-semitrailer population.

It is not possible at this time to estimate the magnitude of the changes, or the timetable over which they will take place. Some have advocated predictions based on experiences of the western states, which historically have been more liberal in their legal limits on truck sizes and weights. Indeed, substantial data have been obtained in research studies, such as that obtained by Vallette et al. *(8)*. Unfortunately, the data are unlikely to be representative or predictive of the rest of the country because of methodological flaws in the study and because the data are predominantly from California *(9)*. For example, the majority of the doubles in California are tankers, flatbeds, or bulk commodity trailers (e.g., rock, gravel), as opposed to the enclosed van trailers typically expected to be used by general commodity carriers.

Beyond these changes, what else might be predicted for the future? Based on the evolving history of trucks in the United States, this author believes that no other major changes will occur by 1990, but perhaps by the year 2000, particularly in the western states.

One change, which will occur gradually, will be the expansion of the designated network. Trucks now largely excluded from two-lane roads will become more frequent users of such facilities. In some states, most or all of the primary system is already "designated." The concept of "access" to designated routes can be expected to gradually increase the roadway mileage used by larger trucks. Similarly, "illegal" use of some roadways will undoubtedly occur, as enforcement is very difficult.

A second gradual change likely to be seen, at least in some areas, is increased use of semitrailers longer than 48 ft. The latter dimension is the minimum ceiling a state can impose. The majority of the states already allow up to 53-ft lengths. Although 48-ft trailers are presently becoming the industry standard, use of 53-ft trailers will probably increase, and off-tracking will then become a greater problem.

Other changes can be predicted based on existing configurations presently operating in limited areas of the country. These include triple trailer combinations and so-called turnpike doubles in which each trailer is up to 48 ft long. Some increase in the weight ceiling may also occur, perhaps in concert with a revised "bridge formula." However, it is doubtful that future trucks will be much wider, as the investment in the infrastructure is too great, and industry pressure for this type of change is weak. The implications of changes in truck characteristics are discussed in the section on Applications of Results to RRR Projects.

Automobiles

The ultimate goal of this subsection would appear to be a set of curves or tables detailing the projected distributions of the vehicle characteristics noted earlier. Indeed, if this paper had been written in 1981, that could have been done. Since then it has become gradually apparent that the projections of that time would not be realized. It was only toward the end of 1984 that the impact of changes in the world economy, new technology, and other pressures on automobile marketing became evident. This dramatic turnabout is not widely appreciated and not yet broadly discussed in the literature. Reasons for these changes from the earlier projections are discussed next, followed by a more qualitative (but quantitative where possible) update on projections. This subsection then concludes with thoughts on the longer-term outlook.

Early Predictions

Following the petroleum energy shortages of the mid- and late 1970s, there was a two-pronged response in the automobile marketplace. First, the industry designed and marketed more fuel-efficient vehicles primarily through "downsizing," accomplished largely by manufacturing front-wheel drive designs. Second, the public sought out more fuel-efficient vehicles, most notably Japanese imports and diesels.

The federal government set standards for corporate average fuel economy (CAFE) that mandated progressively improving fuel economy that would reach 27.5 mpg by 1985. These standards were developed "hand in hand" with the industry in hopes that the standards would be achievable. Projections of automobile sales for 1981 through 1984 by size and weight class were made by the National Highway Traffic Safety Administration (NHTSA) in the mid-1970s and published in 1977 *(10)*.

Glauz et al. used these projections to predict the vehicle-mile-weighted characteristics of automobiles on the roads *(11)*. Examples of these projections are given in Table 1. These projected impacts were fairly large at first, but only modest changes would occur after 1985. Deducting the vehicle loads from the weights given suggests average curb weights of about 3,200 lb in 1985 and 3,000 lb in 1995.

TABLE 1 Projected Average On-Highway Passenger Vehicle Characteristics *(11)*

Year	Inertial Weight[a] (lb)	Engine Displacement (in.^{3})	Engine Net Horsepower
1978	3,880	297.3	143.2
1981	3,732	259.8	125.9
1985	3,508	227.8	109.4
1990	3,377	213.4	103.3
1995	3,352	211.1	102.6

[a]Empty weight plus fuel and coolant plus 300 lb (500 lb for light trucks).

During the late 1970s and early 1980s, most predictions were more extreme. For example, Figure 1 shows a 1985 weight projection prepared by NHTSA in 1981, as quoted by Viner *(12)* and others. It suggests a median weight of about 2,300 lb and a practical maximum of 3,000 lb for automobiles sold in 1985. In 1981 General Motors (GM) predicted that nearly 20 percent of sales would be diesels and 60 percent would be four-cylinder gasoline engines *(13)*. GM also predicted *(14)* that vehicle lengths would decline from 1985 to 1990 (Figure 2) and that tread widths would decrease from

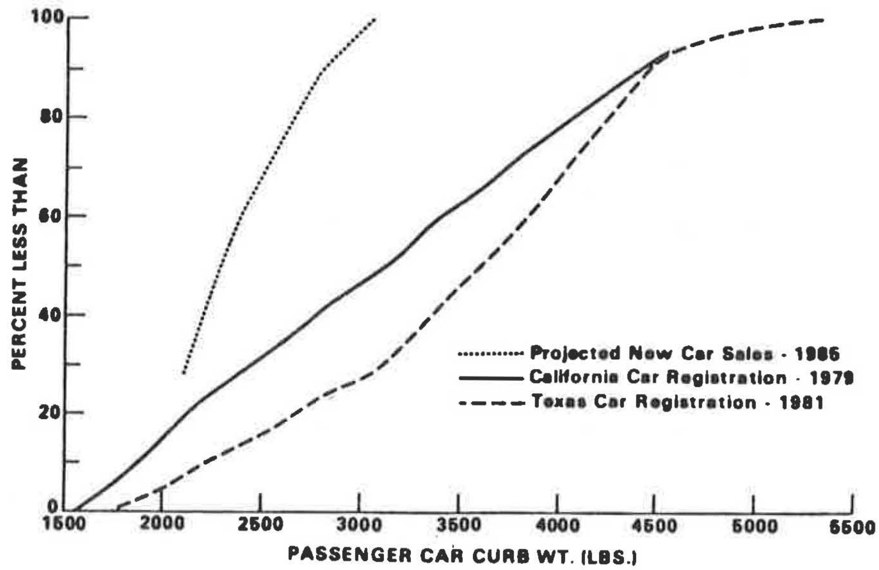

FIGURE 1 Earlier weight projections (12).

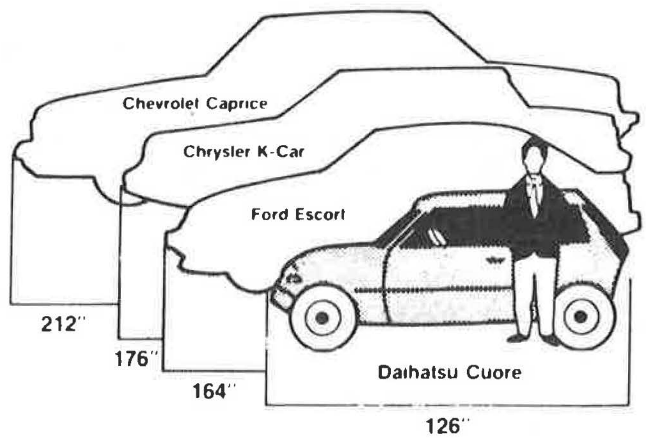

FIGURE 2 Micro vehicle size example (15).

1978 to 1985 but then stabilize (Figure 3). McGee et al. *(4)* compiled data and projections made in the 1980–1982 period, which suggest vehicle lengths will continue to decline from 1970 through 1990, closely in agreement with GM projections.

The most extreme of the earlier predictions are those dealing with mini- or micro-vehicles, alternatively called urban cars, city cars, or "Kei" cars. One example of such a vehicle is the Daihatsu Cuore shown in Figure 2 *(15)*. Among those projecting their substantial impact in the United States were Lave et al. *(16)*, Sparrow and Whitford (15), and Woods and Ross *(17)*. The work of all of these authors was done mostly in the 1982–1983 time period. In 1983 Woods *(5)* predicted that "all the major automobile manufacturers" would introduce vehicles in the 1,000 to 1,500 lb weight range by the 1985 or 1986 model years. Projections of the market share of these vehicles ranged from 6 to 9 percent *(16)* to as high as 60 percent *(15)*.

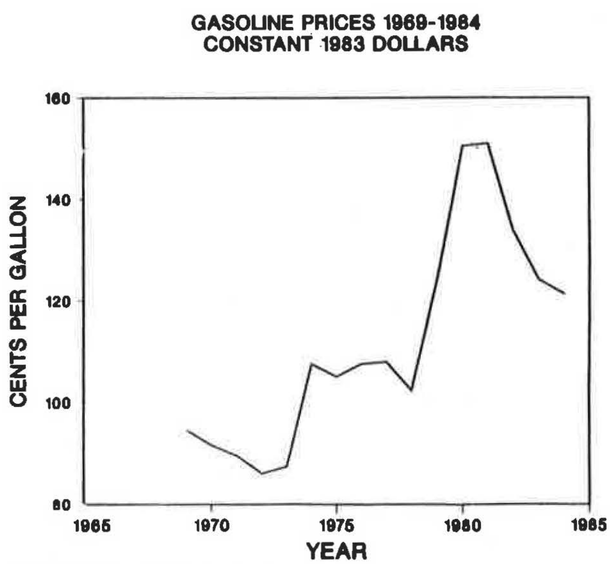

FIGURE 3 U.S. fuel prices (18).

Why Have Opinions Changed?

Current projections represent a significant change from earlier thinking. It is appropriate to examine possible reasons for this near turnabout because these same reasons may dominate longer-term projections.

One reason, of course, is that the marketplace has already responded differently than projected. The public has not demanded the small cars, and manufacturers' downsizing was not as dramatic as many had expected. The Japanese, faced with "voluntary" import quotas to the United States, have concentrated on their larger, more luxurious and profitable models.

Hemphill *(16)* reported that the three major criteria people used in choosing a vehicle in 1980 were, in order, (a) fuel economy, (b) low purchase price, and (c) quality and dependability. In 1981 fuel economy had dropped to third on the list. Greene et al. *(18)* reported the dramatic changes in fuel prices (see Figure 3). Since their report, world crude prices have been cut in half, and gasoline was selling in early 1986 for prices at or below those of the early 1970s.

Technology advances in the industry have resulted in improved fuel economy independent of vehicle downsizing *(19–21)*. The biggest technological impact has been the rapid growth in the use of electronics and microcomputers. Altshuler and Roos *(19)* point out that microprocessors were added to engines beginning in the mid-1970s, to transmissions in the early 1980s, and are now available for some suspension systems. Further, the use of microprocessors and electronic controls can significantly reduce the demands of auxiliary systems on the power system. A current example is the electric radiator fan, which has become nearly universal and operates only when auxiliary cooling is required. Microprocessor-controlled power steering is available in some Japanese models; it provides maximum assist in very low speeds, such as when parking, and very little assist at highway speeds. Mercedes Benz and some top-of-the-line Ford products now offer microprocessor-controlled antiskid power brakes *(22)*. Most other auxiliary systems are likely to come under computer control in the future.

Other technological improvements discussed by Altshuler and Roos *(19)* include engine improvements such as the four-valve-per-cylinder engine, turbocharging, and electronic fuel injection, which is now becoming quite common *(21)*. Advanced research and development is presently underway on adiabatic engines with ceramic liners and other ceramic parts. Such engines can run at much higher temperatures, and thus convert a greater proportion of the heat produced into useful energy. In fact, such engines would not need a cooling system. Continuously variable transmissions, when coupled with microprocessor control and advanced materials, will enable the engine to always run at its optimum speed, regardless of vehicle speed. Carbon fiber composites provide strength-to-weight ratios far in excess of metals. Although not yet generally cost-competitive with metals, composites are expected to be used increasingly. For example, the Chevrolet-Corvette uses composite materials in its springs.

Another major advance is in improved aerodynamics. The drag coefficient (C_d) of the average vehicle on the road is about 0.5. The average C_d of vehicles presently being marketed is about 0.4. Some production vehicles (e.g., the Audi 100) have C_d values as low as 0.3. There are prototypes as low as 0.15, and researchers are hoping to achieve values below 0.1. Within 20 years, it is projected that the average new automobile will have a C_d of 0.2 or less *(18)*, which, when compared with the vehicles now being marketed, would have up to 25 percent better fuel economy at highway cruising speeds because of that factor alone.

In summary, fuel economy is no longer the pressing issue it was in the mid- and late-1970s when most projections were made. Federal fuel economy standards have been relaxed. Rapid technology advances have enabled fuel economy savings beyond that offered by downsizing. The purchaser can obtain reasonable fuel economy without buying a small car. Moreover, manufacturers now push the more expensive (and profitable) larger cars at a sacrifice in fuel economy.

Current Data and Revised Projections

Recent data show that the earlier predictions are not proving accurate—they greatly overestimate the amount or rate of change that would take place in vehicle characteristics. Taylor *(21)* noted that the average weight of American automobiles for model year 1980 was about 3,200 lb, and that has not changed appreciably in the 4 years hence. The federally mandated CAFE of 27.5 mpg was not met in 1984 and was relaxed to 26.5 mpg in 1985. The sales of domestic minicompacts declined from nearly 5 million in 1978 to zero in 1982 (see Figure 4). Sales of domestic subcompacts have declined appreciably from 1980 onward. The growth has been in sales of the compact-sized vehicles and, to some extent, in large vehicles. A similar story is true for imported vehicles (Figure 5).

The University of Michigan has conducted biannual Delphi surveys of automobile industry forecasts of more than 100 automotive industry experts *(23)*. Examples of how drastically opinions have changed are given in Table 2, and predictions for 1990 model year vehicles are compared.

The preceding discussion focuses on automobiles. However, the purchaser of a vehicle for personal transportation has other options, such as pickup trucks, vans, and special purpose vehicles (e.g., "jeeps"), which, collectively, are termed "light trucks" by NHTSA. In 1984 the latter accounted for 25.8 percent of all light-duty vehicles sold, the result of a fairly consistent increase from 20.7 percent in 1978 *(24)*.

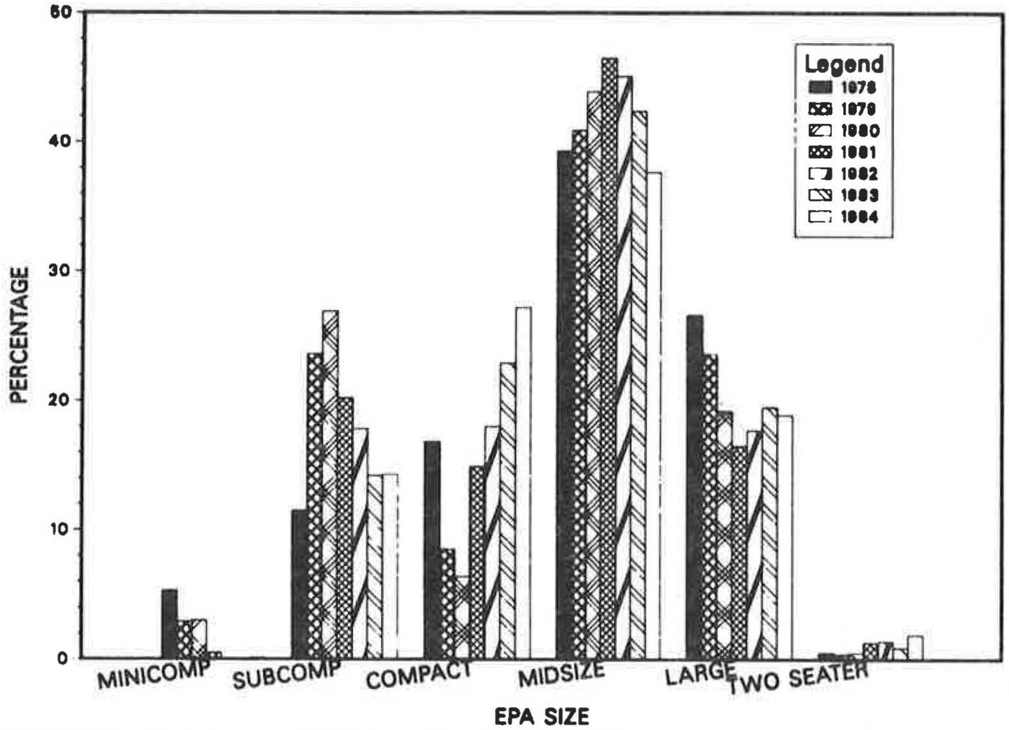

FIGURE 4   Market shares of U.S. domestic automobiles (24).

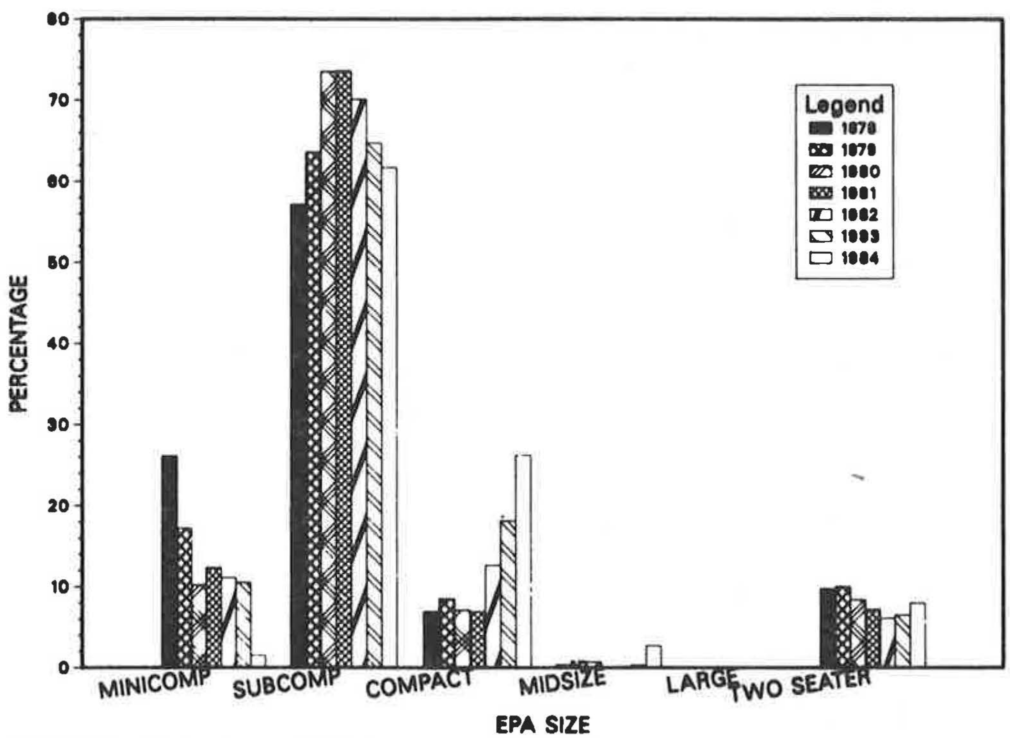

FIGURE 5   Market shares of U.S. import automobiles (24).

TABLE 2 Automotive Industry Opinions

	Year of Survey		
Topic	1979	1981	1983
Price of gasoline in 1990 (1983 $/gal)	3.45	3.30	1.60
1990 fuel economy (mpg)			
Domestic	30	35	30
Japan	NA	36–39	32
1990 median vehicle weight (lb)	2,515	2,250	2,419
Percent of 1990 domestic sales accounted for by			
8-cylinder engines	5	3	10
6-cylinder engines	25	20	35
Diesel engines	25	20	10
Full size plus intermediates	30	24	36
Mini-subcompacts plus commuters	NA	15	4

NOTE: NA = not applicable.

Revised projections of most other vehicle characteristics have not appeared as yet in the literature. It is clear that the process of downsizing, and possible future "upsizing," involves a number of characteristics such as length, width, weight, interior volume, and the like. Moreover, the correlations between these characteristics are not perfect *(25)*. Nevertheless, it is likely that the authors who overestimated the future decrease in vehicle weight, for example, also overestimated the decrease in length, width, and the like.

The one vehicle-related characteristic that has been addressed by highway safety experts more than any other, aside from weight, is driver eye height. Recent studies by Farber *(26)*, Khasnabis et al. *(27)*, Olson et al. *(28)*, and Weaver et al. *(29)* have been reported. They generally agreed that the lower bound on driver eye heights has not changed appreciably for several years and is not likely to change in the future.

The Longer-Term Outlook

It is likely that the basic characteristics of size and weight will not change drastically in the next 15 years.

At the end of 1982, the world's proven petroleum reserves represented a 34-year supply at current production rates, the same as it was in 1969–1971. Moreover, the fraction of the petroleum reserves available for automobiles will increase dramatically in the years ahead. In the last 10 years, there have been substantial movements toward alternative energy sources for space heating, electricity generation, industrial process energy, and agriculture. Vehicles are much more fuel-efficient now than 10 years ago (twice as efficient in the United States). For all of these reasons, there should be no long-term shortage of gasoline in the next few decades.

Speed limits are likely to increase, at least on rural Interstates *(30)*. As a result, there will be some increase in demand for more power and comfort, further suggesting a decline in the downsizing mode, and probably a return to larger cars.

The vehicles now being sold will still be in use in large numbers by the year 2000. The life cycle of an automotive design is on the order of 25 years *(19)*. It takes approximately 5 years to bring a new design to market; it then typically continues in production for 6 to 8 years. The vehicles continue to be driven for 12 or more years.

APPLICATION OF RESULTS TO RRR PROJECTS

Trucks

1. *Low-speed off-tracking.* Increased off-tracking is experienced by longer vehicles—especially those with large spans between successive axles. Of the trucks expected to be frequently encountered in the near future, the 48-ft semitrailer is of greatest concern. Redesign of intersections and widening of sharp curves may be required to eliminate encroachment on the opposing or adjacent lane, on curbs or medians, or on the shoulder.

As an illustration of the effect of configuration on the amount of off-tracking, consider the simple case of a constant radius curve *(31)*. The data in Table 3 show the amount of off-tracking (i.e., the offset between the paths followed by the front wheels and the rear wheels) for a number of configurations on a 200-ft radius curve. The 48-ft semitrailer would encroach on either the shoulder or the adjacent lane by more than 1 ft; the fairly common 53-ft semitrailer would encroach by nearly 2.5 ft. In this case, the lane may require a greater width at this location to accommodate such trucks. (Note that the twin trailer combination off-tracks substantially less.)

TABLE 3 Illustrative Off-Tracking Amounts

Configuration	Offtracking (ft)	Lane Width[a] (ft)
17-ft car	0.25	–
30-ft single unit truck	1.00	9.50
40-ft bus	1.57	10.07
Tractor/40-ft semitrailer	3.40	11.90
Tractor/48-ft semitrailer	4.87	13.37
Tractor/53-ft semitrailer	5.96	14.46
Tractor/twin 28-ft trailers	2.54	11.04

[a]Required to accommodate an 8.5-ft-wide vehicle.

2. *High-speed off-tracking.* This phenomenon requires higher speeds *(32)*, and could be a problem on curves or ramps. The off-tracking magnitudes are usually not large, but are greater for multiple-unit vehicles. It could lead to overturn of the rear trailer if the rear wheels contact an obstacle such as a curb.

3. *Vehicle width.* Research studies have found no significant problems induced by the added 6 in. in width. Lane width suitable for 96-in. widths are generally also acceptable for 102 in. Off-tracking will be greater (by 6 in.), but this is usually a small fraction of the total off-tracking problem.

4. *Vehicle weight.* Collisions between automobiles and heavy trucks have always been a concern, and will continue to be so. The allowable weight increase from 73,280 to 80,000 lb is not of great concern as this is only a small increment over the already great differential with, for example, a 3,000-lb automobile. However, as truck volumes increase, the potential for automobile–truck collisions becomes greater. Also, there is concern about the ability of heavier trucks to maintain speed on grades. The resulting speed differentials between vehicles suggest a higher accident probability at such locations.

Roadside hardware is usually designed for automobile impacts. It generally will not redirect 73,280-lb vehicles, let alone 80,000-lb vehicles. This fact, coupled with increased truck volumes, suggests that substantial work is needed to design and install hardware that will safely accommodate both trucks and light automobiles.

5. *Rearward amplification*. In a severe lateral movement, such as in an evasive lane change, the second trailer in a doubles combination will be subjected to an amplified lateral acceleration and displacement *(33, 34)*. If severe enough, it could lead to rollover of the rear trailer. It is not clear how highway design can affect this phenomena—it is more a question of vehicle design.

6. *Braking*. Properly designed and adjusted brakes provide comparable stopping distances for the newer configurations so this should not be considered a new issue *(34)*.

7. *Overall safety of doubles*. It is unlikely that twin trailer combinations will be found to be appreciably less safe than semitrailers *(34)*.

Automobiles

Despite a great diversity of opinion concerning future vehicle characteristics, most researchers do not anticipate the need to revise highway design standards to any significant degree *(4, 17)*. Those areas or standards that have been studied are briefly examined next.

1. *Lane width*. A few authors *(5, 17)* have suggested that narrower lane widths would be acceptable, based on present and projected automobile widths. However, they also point out that if trucks and buses are allowed to use these lanes, no changes in the standards should be made.

2. *Vehicle length*. Even though present and future automobiles are somewhat shorter, no changes in standards are recommended because they are so weakly dependent on vehicle length *(4)*.

3. *Driver eye height*. The present design height of 42 in. could be reduced to 39 or 40 in. However, this change would have minimal effect on sight distance *(26, 27)*.

4. *Underclearance*. Several authors *(4, 5, 28)* have noted that underclearances of 4 in. are not uncommon. McGee et al. *(4)* report that the median underclearances for 1983 automobiles were about 4.9 in. (domestic) and 5.2 in. (foreign); about 10 percent of domestic and foreign vehicles had underclearances of 4 in. or less. If the present design object height of 6 in. is based on underclearance, it should be reduced.

5. *Stopping sight distance*. In addition to driver eye height and object height, stopping sight distance depends on stopping ability. There is some criticism of present AASHTO standards relative to stopping ability *(4, 28)*, claiming that real drivers may require more distance than the standard assumes. This has nothing to do with changes in vehicle characteristics. However, to the extent that future vehicles use antiskid brakes, stopping distances should decrease, perhaps counterbalancing these criticisms. (See also Item 9.)

6. *W-beam guardrail*. Smaller automobiles tend to have lower bumper heights, and some may have a tendency to submarine under W-beams set at the present standard height of 27 in. *(5, 17)*. On the other hand, if the height were lowered, some larger vehicles may be prone to vaulting the barriers *(35)*. It appears that further research is required in this area.

7. *Sideslopes*. Burtch et al. *(36)* found that smaller vehicles are not more likely to overturn on sideslopes than larger vehicles; Woods *(5)* suggested otherwise. Further research may be required in this area, also.

8. *Roadside hardware.* The safety issue that may be most affected by smaller (lighter) vehicles is roadside hardware or fixed-object collisions *(5, 12, 17, 36)*. Present design standards for utility and luminaire poles are probably inadequate for vehicles weighing substantially less than 2,000 lb—for example, microvehicles in the 1,200 to 1,600 lb range. Nevertheless, such vehicles are not presently anticipated to be a significant fraction of the highway traffic mix. Sign supports, on the other hand, may not be designed appropriately for any vehicles under 2,000 lb *(5)*. Because several present vehicles weigh less than this amount, this design standard might reasonably be reviewed.

9. *Automobile braking ability.* As an increasing number of automobiles use antiskid braking systems—a development just now beginning with certain Mercedes and Ford products—stopping distances will decrease, especially on wet pavements. This could affect design standards such as stopping sight distance. However, the effect on safety is likely to be mixed. If all vehicles had such brakes, many current accidents would be converted to "near misses" or accidents of less severity. On the other hand, if some vehicles have substantially shorter stopping capabilities than others, an increase in rear-end accidents would be expected.

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