something you walk away from if you are an older person wearing safety belts. In an air bag there is a broadly distributed load and no problem.

POTENTIAL IMPACT OF THE MICROVEHICLE ON ROADWAY FACILITIES

Donald L. Woods and Hayes E. Ross, Research Engineers, Texas Transportation Institute, Texas A&M University

Paul Dexler, in a July 1981 Motor Trend Magazine article (1), says, "The Micros Are Coming." For those of us in the highway research field, this means we are already behind. To have the information necessary to guide designers when the micros are in wide use, several years and millions of dollars of research will be needed.

This paper explores the potential impact of micros on highway design. An attempt has been made to present logical and reasonable projections for changes in design which can be expected should the microvehicle become a significant part of the traffic stream.

Before evaluating the potential impact of microvehicles, it was necessary to define the basic design characteristics of a microvehicle. Based on the data provided by Dexler, the following summary statistics are given for minivehicles and microvehicles. These data form a basis for selecting a design microvehicle.

For the purposes of this paper, the values listed in Table 1 for the microvehicle will be used as the design microvehicle. It probably represents the low side of the microsize vehicles that can be expected in the next decade and therefore may well be the logical microcar design vehicle.

Driver eye height for the design microvehicle can be estimated from the vehicle height. The Society of Automotive Engineers (2) suggests that a driver's eyes will typically be approximately 10 in. (25.4 cm) below the roof of the vehicle. From Table 1, microvehicle height is approximately 53 in. (134.6 cm). The eye height then would be approximately 43 in. (109.2 cm), or 3.58 ft. (1.1 m). This eye height is remarkably similar to the eye height of minivehicles and the design eye height that has been tentatively adopted for the new AASHTO highways and street design policy. Therefore, the problem of driver visibility from the microvehicle would not be expected to be any different than for the present minivehicles.

The design microvehicle is 6 in. (15.2 cm) narrower and approximately 2 ft. (0.61 m) shorter than the present minisize vehicles. The doors on the microvehicle will probably need to be essentially the same size of those on the minisize vehicles. A recent study (3) indicated that the partially open position of minivehicles is about 47 in. (119.4 cm) wider than the closed door width, and the fully open position is about 83 in. (210.8 cm) wider. Thus the two-door open design microvehicle dimensions are 102 in. (259.1 cm) or 8.5 ft. (2.6 m) partially open and 138 in. (350.5 cm) or 11.5 ft. (3.5 m) fully open.

These basic dimensions permit an evaluation of the future needs of highway design features to accommodate the microvehicle.

Geometric Design

Stopping Sight Distance

The basic microvehicle design characteristics previously summarized suggest that a 3.5 ft. (1.1 m) eye height would be appropriate, since AASHTO has already adopted an eye height of 3.5 ft. (1.1 m) as the basic design eye height for the future. General application of this criterion would appear to satisfy the stopping sight distance needs of microvehicle drivers.

Passing Sight Distance

An eye height and object height of 3.5 ft. (1.1 m) previously adopted by AASHTO would appear to provide a relatively safe passing sight distance for the microvehicle driver. The lack of adequate visibility of restrictive pavement markings and the changes in acceleration characteristics of the smaller vehicles will probably be far more significant. No additional changes in the passing sight distance criteria are seen to be necessary to accommodate the microvehicle.

Lane Widths

Lane width requirements for the microvehicle for low-speed operation could be as narrow as 7 ft. (2.1 m) -- a vehicle 5 ft. (1.5 m) wide plus 1 ft. (.31 m) clearance on each side. It is, however, very doubtful that microvehicles will ever make up a majority of the traffic stream. The compact will probably be the least size of vehicle on which lane width will be predicated. Thus an 8 ft. (2.4 m) lane in the absence of trucks or buses is the least probable lane width that can be effectively operated. For high-speed operation (i.e., over 35 mph (56.3 km/h)) a 2 ft. (0.61 m) clearance on each side of the vehicle is needed for normal tracking. Thus 10 ft. (3.1 m) as a minimum should be used. Where trucks or buses are present in substantial percentages, the lane width would be dictated by the maximum 8 ft. (2.4 m) truck width. For low-speed operations (i.e., 30 mph (48.3 km/h) or under) a width of 10 ft. (3.1 m) is acceptable. For high-speed operations 11 or 12 ft. (3.4 or 3.7 m) will need to be provided.

TABLE 1. TYPICAL DIMENSIONS FOR MINI AND MICROVEHICLES (after Dexler (1))

VEHICLE TYPE	VEHICLE LENGTH (in.)	VEHICLE WIDTH (in.)	VEHICLE HEIGHT (in.)	VEHICLE WHEEL BASE (in.)	VEHICLE WEIGHT (in.)	WHEEL TRACK (in.)
MINI	148	61	53.6	89.5	1630	52.5
MICRO	126	55	53.0	81.5	1200	48.0
DIFFERENCE	22	6	.6	8.0	430	4.5

Metric Conversions: 1 in. = 2.54 cm
1 lb_m = .454 kg

Parking Stall Dimensions

The basic microvehicle parking stall dimensions would be 8 ft. by 10 ft. (2.4 m by 3.1 m). It is very doubtful if the microvehicle would ever be dominant enough in the traffic stream to justify these dimensions for design. Rather, it is likely that the subcompact vehicle dimensions of 8 ft. by 15 ft. (2.4 m by 4.6 m) will prevail for the foreseeable future.

Changes in Geometric Standards

In summary, geometric design standards are not expected to change significantly as a result of the presence of the microvehicle in the traffic stream. In the urban environment and when speeds are low it may be possible to reduce the lane width down to 8 ft. (2.4 m) in the absence of trucks or buses.

Highway Appurtenances

Sign and Luminaire Supports

According to AASHTO (4), "Satisfactory dynamic performance is indicated when the maximum change in momentum for a standard 2250 lb. (1020 kg) vehicle, or its equivalent, striking a breakaway support at speeds from 20 mph to 60 mph (32 km/h to 97 km/h) does not exceed 1100 pound-seconds (4893 N-sec), but desirably does not exceed 750 pound-seconds (3336 N-sec)."

As used in the Specifications, "breakaway supports" is a generic term meant to include all types of sign supports whether the release mechanism is a slip plane, plastic hinges, fracture elements, or a combination of these. The Specification states that "Breakaway structures should also be designed to prevent the structure or its parts from penetrating the vehicle occupant compartment." The Specification also alludes to the unacceptability of vehicle rollover following impact with the test article.

The AASHTO criterion implies that the change in velocity of an impacting vehicle should not exceed 10.7 mph (17.2 km/h), but preferably not exceed 7.3 mph (11.7 km/h). Recent test guidelines published by NCHRP (5) recommend change in velocity limits similar to AASHTO for sign and luminaire supports.

The question is then: What velocity change can be expected if a microvehicle impacts a support designed to the current AASHTO criteria? To make an estimate of this change an assumption must be made with regard to the kinetics of the support (in the absence of an actual vehicle and full-scale crash tests). It is assumed that the impulse (change in momentum) during impact is a function of the support design and independent of the impacting vehicle, i.e., it is not a function of the size or shape of the vehicle. This assumption is believed to be valid for most breakaway type supports. Its validity for "yielding" or "base bending" supports is less certain. Based on this assumption, velocity change was computed for three vehicle sizes using the formula

$$\text{change in momentum} = \text{impulse} = m\,(\Delta V) = M$$

or

$$\Delta V = \frac{\Delta M}{m} = \frac{\Delta M(g)}{W}$$

where g = gravitational acceleration
W = vehicle weight

Computed values are given in Table 2.

TABLE 2. VELOCITY CHANGE AS RELATED TO VEHICLE WEIGHT

VEHICLE WT. (lb)	VELOCITY CHANGE (mph) Based on M = 750 lb-sec [1]	Based on M = 1100 lb-sec [2]
4500	3.7	5.4
2250	7.3	10.7
1200	13.7	20.1

[1] Preferable according to AASHTO (4)

[2] Limit according to AASHTO (4)

It can be seen from Table 2 that sign and luminaire supports that were designed to satisfy the "preferable" limits will probably produce microvehicle velocity changes in excess of the upper limit (10.7 mph). In truth, many sign and luminaire supports now in use just barely meet the upper limit criterion. For those designs, velocity changes for the microvehicle can be expected to be approximately twice the recommended limit.

In addition to the hazard of increased velocity change, microvehicles will have a greater propensity for rollover following impact with sign and luminaire supports. Recent tests have shown that smaller vehicles upon impact with sign supports tend to spin out, and in some cases roll over violently if the impact is off center (6).

Longitudinal Barriers

Lateral and longitudinal vehicle decelerations are primary measures of impact severity for longitudinal barrier collisions. Of these, lateral decelerations are usually more critical. The following discussion therefore focuses on variations in lateral decelerations which may be expected as a function of vehicle size.

As a general rule lateral vehicle deceleration depends on the velocity, weight, and encroachment angle of the vehicle and the lateral deflection of the barrier. Estimates of barrier lateral deflection will be made by use of the following approximate formula:

$$\frac{1/2\, M_K (V_K \sin \theta_K)^2}{D_K} = \frac{1/2\, M_U (V_U \sin \theta_U)^2}{D_U}$$

where V = impact velocity
θ = impact angle
D = lateral barrier deflection
M = mass of impacting vehicle
K = subscript to denote known data
U = subscript of variables

The strong post W-beam barrier with wood posts, known as the G4(1W), is a widely used longitudinal barrier system. It will therefore be used to make the following comparisons.

The 1977 AASHTO "Guide for Selecting, Locating and Designing Traffic Barriers" provides the following information for a particular crash test of a G4(1W) barrier:

M = 4123 lb
V = 88.1 ft/sec
D = 2.8 ft
θ = 22.2 degrees

Solving the equation for Du and substituting the above data into the equation results in the following equation:

$$D_u = 6.128 \times 10^{-7}\ W_u\ (V_u \sin \theta_u)^2$$

where D_u = deflection in feet of G4(1W) barrier
W_u = weight of impacting vehicle in pounds
V_u = velocity of impacting vehicles in feet per sec
θ_u = angle of impact in degrees

The estimated deflections for a W-beam barrier of the G4(1W) type impacted at 15°, 60 mph by vehicles weighing 1200, 2250 and 4500 lb. (545, 1022 and 2250 kg) are presented in Table 3.

TABLE 3. EXPECTED DEFLECTION OF A G4(1W) BARRIER ON IMPACT AT 15° AND 60 MPH

VEHICLE WT. (lb)	EXPECTED DEFLECTION OF W-BEAM BARRIER (ft)
450	1.4
2250	0.7
1200	0.4

The AASHTO Barrier Guide also presents an equation for estimating the average lateral acceleration on impact with a W-beam barrier of the G4(1W) type.

$$G_{lat} = \frac{V^2_f \sin^2 \theta}{2g\ ((A \sin \theta - 0.5B\ (1 - \cos \theta) + D))}$$

where G_{lat} = lateral acceleration on vehicle in G's
A = distance in feet from front of vehicle to 6.6 (0.45 x (length)
B = vehicle width in feet
D = expected lateral barrier deflection in feet
V_f = velocity of impacting vehicle in feet per second
θ = impact angle with barrier

For the G4(1W) guardrail system the lateral accelerations for a 60 mph impact at 15° and various vehicle weights were computed and are given in Table 4.

TABLE 4. EXPECTED AVERAGE LATERAL ACCELERATION ON IMPACT WITH A (G4(1W)) BARRIER AT 15° AND 60 MPH

VEHICLE WEIGHT (lb)	A (ft)	B (ft)	D (ft)	G_{lat} (g's)
4500	8.0	6.5	1.4	2.4
2250	5.5	5.1	0.7	4.0
1200	4.7	4.6	0.4	5.3

Similar data for rigid barrier impacts (i.e., D=0.0) are presented in Table 5.

TABLE 5. EXPECTED LATERAL ACCELERATION ON IMPACT WITH A RIGID BARRIER-SAFETY SHAPE OR VERTICAL WALL

VEHICLE WT. (lb)	A (ft)	B (ft)	G_{lat} (g's)
4500	8.0	6.5	4.1
2250	5.5	5.1	6.1
1200	4.7	4.6	7.1

When compared with recommended lateral deceleration limits of 5 g's (7), the values for the microvehicle are what may be termed "marginal". It can be seen that severity of impact increases as the vehicle size decreases and as the stiffness of the barrier increases. Predicted lateral deceleration of the microvehicle upon impact with a rigid barrier (such as the concrete safety shape) is considerably higher than recommended limits. Stability of the microvehicle upon impact with the concrete safety shape barrier will also be of critical concern. It is well known that the propensity for rollover of vehicles striking the concrete safety shape barrier increases as the vehicle size decreases.

The geometry of the barrier is also of major concern. Figure 1 shows the typical W-beam installation and the distribution of midheight of the

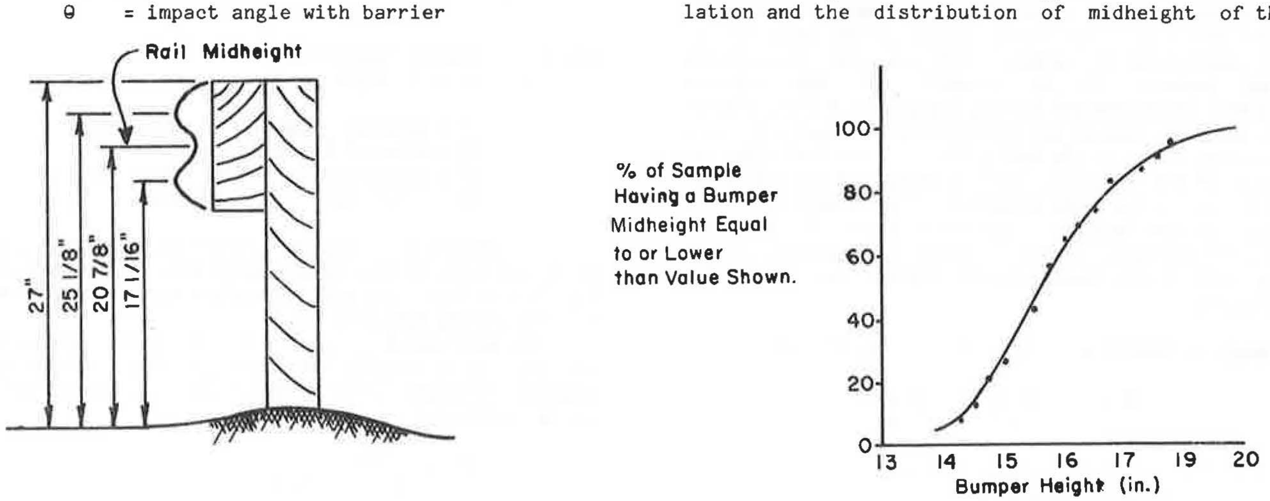

FIGURE 1. CUMULATIVE DISTRIBUTION OF BUMPER HEIGHT OF MINIVEHICLES

bumper on cars between 1100 and 2250 lbs. (545 and 1022 kg) (small cars). Note that the bumper mid-height of a full 80 percent of the vehicles in this weight range is lower than the center of the lower bulb of the W-beam barrier.

This suggests that the smaller cars including the microvehicles may have an increased potential to submarine under the barrier and snag on the posts. Indeed, testing has demonstrated this behavior on a Honda Civic for an opening of only 13 in. (33 cm) from the bottom of a rigid concrete rail to the bridge deck. This suggests that most W-beam barriers and W-beam transition sections may be too tall for many small cars. The microvehicles will only add to the severity of the existing problem.

Strong-post W-beam barriers (e.g., the G4(1W) and the G4(1S) roadside barriers) can possibly be modified by the addition of a rub rail to accommodate the microvehicle should the underride or submarine problem materialize. The same modification may also be necessary on weak-post systems (e.g., the G2 and G3 roadside barriers). Use of the thrie-beam in lieu of the W-beam will undoubtedly reduce and may eliminate this problem. It may also be necessary to adjust the cable spacing of the G1 system for the microvehicle. Need for the above modifications will also depend to a large extent on the profile of the microvehicle. If the hood and fender heights are similar to present subcompact models the problem will probably be minimal. Answers to these questions must come from analysis, including appropriate computer simulations and ultimately full-scale tests.

Crash Cushions

Most of the commercially available crash cushions can be adapted to accommodate a 1200 lb. (545 kg) design vehicle. This process is, however, expensive as a retrofit but will probably be practical if the unit must be replaced. A typical crash cushion provides 7 to 10 g's of longitudinal deceleration on frontal impact. Assuming the 10 g level to be typical for a 2250 lb. (1022 kg) design vehicle, the resisting force can be calculated.

$$F = ma$$

where F = resisting force in pounds
m = mass of impacting vehicle
a = acceleration

For a 2250 lb. (1022 kg) design vehicle, the resisting force is:

$$F = \frac{2250}{32.2}(10)32.2 = 22{,}500 \text{ lbs.}$$

The acceleration on a 1200 lb. (545 kg) vehicle is:

$$a = \frac{(22{,}500)32.2}{1200(32.2)} = 18.8 \text{ g's}$$

A crash cushion that is safe for the 2250 lb. (1022 kg) vehicle is decidedly unsafe for the 1200 lb. (545 kg) microvehicle. The problem is not, however, that difficult to solve. For example, an inertia barrier designed for a maximum 10 g deceleration to accommodate a 2250 lb. (1022 kg) and 4500 lb. (2043 kg) design vehicle impacting at 60 mph results in the Figure 2 designs.

A design to accommodate the 1200 lb. (1022 kg) microvehicle results in the Figure 3 design.

While the number of modules involved is only changed by one, the design to accommodate the 1200 lb. (545 kg) vehicle is 27 ft. (8.2 m) long as compared to 21 ft. (6.4 m) for the subcompact vehicle

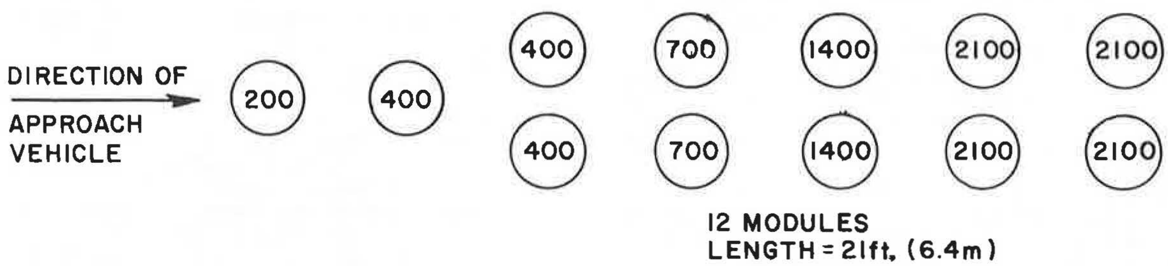

FIGURE 2. INERTIA BARRIER DESIGN FOR 2250 lb. (1022 kg) DESIGN VEHICLE

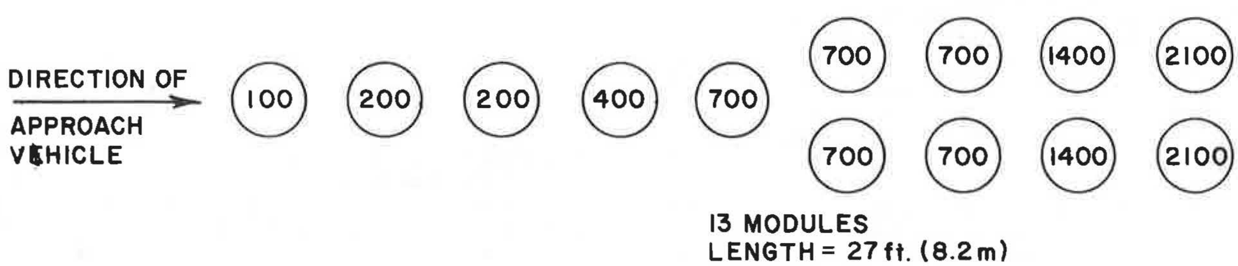

FIGURE 3. INERTIA BARRIER DESIGN FOR 1200 lb (545 kg)DESIGN VEHICLE

design. This example illustrates that for inertial barriers, at least, the retrofit to accommodate the 1200 lb. (545 kg) microvehicle will be rather easy to accomplish.

Driver Visibility

Driver eye height for microvehicles is essentially the same as for minivehicles. For this reason, driver visibility problems above and beyond those created by the minivehicles can only be created by blockage of the line of sight by elements of the vehicle. This will probably not require any significant changes in the traffic control device location. Nor is it expected to appreciably alter visibility of the roadway features.

The reader should recall that the standards for sight distance, marking no-passing zones, and stopping sight distance will be changed by the new eye height and object height criteria to be published by AASHTO in the near future. The advent of significant numbers of microvehicles in the traffic stream will probably not create any appreciable difference in the geometric design and operational standards required to satisfy the needs of the minivechicle.

Restricted Use of Microvehicles

Many have suggested that microvehicles should be restricted from the highway system and limited to low-speed urban roadways. Several types of restrictions have been discussed.

1) Restriction by highway type.
2) Restriction to the urban limits.
3) Restriction by operating speed

All three of these restrictions seem to be predicated on the concept that the differential in weight between the microvehicle and other vehicles in the traffic stream results in a serious safety problem if high-speed operation is allowed. The three restrictive methods mentioned above are all attempts to keep the microvehicle out of high-speed situations.

The concept of restriction has many social implications. For example, the microvehicle as the second vehicle in the household would not present a serious problem if such restrictions were implemented. History has taught us that the first to adopt new technology (i.e., new car sizes) are the young. This is for two reasons: First, they have limited funds, thus lower vehicle cost and greater fuel economy are of prime importance to them. Second, these young people do not consider the smaller vehicle to be a second vehicle but rather simply a source of transportation. Restrictions to a particular area or particular type of highway would be perceived as a restriction on their right of choice of which vehicle to purchase.

Another factor that will tend to limit restriction of the microvehicle is low probability of being involved in an accident. There is only a three percent chance of any given vehicle being involved in an accident of any type in any given year. The combination of these factors will make it very difficult, if not impossible, to implement restrictions of any type. The enforcement problem would also be a most challenging one.

Summary

Based on a tentative review, it appears that no major changes in geometric design standards will be required as a result of the microvehicle. Some highway appurtenances will likely need to be modified if current performance standards are to be maintained. Many sign and luminaire supports will likely have serious deficiencies. W-beam barriers will be adequate for microvehicle impacts but a rub rail may be necessary for the strong post guardrail systems to ensure safe impacts. The thrie-beam will likely be used more in lieu of the W-beam due to its increased height and reduced ground clearance. High decelerations and an increased rollover potential will be a major concern for microvehicle impacts with the concrete safety shape barrier. Adjustments may be necessary in the relative heights of the cables used in the cable roadside barrier.

Crash cushions will need to be redesigned to accommodate the microvehicle. In the case of the inertia barriers at least, this change is more one of length than the provision for additional elements.

Driver visibility requirements for the microvehicles are not expected to be greater than with the minivehicles that are presently in the traffic stream. The limited changes needed on the highway system to adapt to the microvehicle, combined with the social and enforcement problems of restricting their use to a particular area or a particular part of the road system, make restriction a highly questionable practice. Overall, the impacts of the microvehicle on design standards should be fairly minor and might actually allow the use of lanes as narrow as 8 ft. (2.4 m) to increase the capacity of low-speed urban streets in the absence of trucks and buses.

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DISCUSSION:

QUESTION: Isn't there a problem with the smaller vehicles being subject to more rollovers?

MR. WOODS: It does roll over more frequently. California data supports that. All the other states have reported a significant number of rollovers after impact with safety devices or other vehicles. All of what we projected is based on the vehicle remaining stable. That is not necessarily a valid assumption when you start getting into these very low weights and off-center hits. That is correct and is a very valid point. The problem that you get into with trying to detect the stability problems is very complicated, however, and well beyond the scope of what we were trying to address in this session. It is certainly a fundamental problem. We will have to weaken the devices; they probably will have to be weaker than what we have projected in the paper; that is, taking the 1,100 and 750 second criteria. But that was, and the question came up earlier, what was the survivable deceleration. The criteria that we now have, as much as anything, is based on the stability of the vehicle after impact. Therefore, we have incorporated some of that thinking into the criteria.

QUESTION: What has or can be done to make utility poles breakaway design?

MR. WOODS: The utility pole area has some real built-in problems. It's obvious we can treat them, we know how to do that, that's not the problem. The problem is, people that work on utility poles have union rules that don't allow them to climb them if they are weakened and that creates a very basic problem. If you put in a weakening mechanism to make it safe, what do you do with the lineman when he goes out for repairs? This is not significant in every state, it is very significant in some states. We do not have a satisfactory mechanism at the present time for these very light vehicles in that respect. We're probably exceeding the mass of the pole--the mass of the pole probably exceeds what we can reasonably hope to be safe for a vehicle of 1,000 or 1,200 pounds which means scaling down the size of the elements drastically, but more practically, get it away from the highway. That's where we're going to push, I think, in the future. We forget sometimes that we give the utilities the privilege of being on our right of way but we don't have to give it. We can take it back and force them to do things or lose their utilities, to make them safe, especially under certain circumstances.

QUESTION: What effect would there be on sign post design?

MR. WOODS: They do have to be substantially weaker, there's no question about that. Probably we're talking about changing the material property in order to achieve the fracture at relatively low energy levels and at the same time resist bending satisfactorily. Probably, also we're going to have to cut the weight down even further. Where we now talk about 3 pounds per foot being the basic single post that's safe, we may have to think in terms of 2 pounds or less. This means we have more vibration problems and several other of the normal installation problems becoming very difficult. The other thing that looks very shaky is the fracture type, the wood supports. Four by six is marginal for a 2,250 pound vehicle, now we pull it down to 1,200 or 1,700 even, and it becomes at best survivable. The injury rate is going up drastically with the smaller vehicles.

In terms of making them more survivable for a 15 degree hit? The logic of the system says you have to yield a little bit in order to get these lateral decelerations down below 5 G's. Maybe the criteria are bad, that's a possibility. Assuming the criteria are good, then it probably would mean adding on to it to allow the vehicle to penetrate slightly, which increases our maintenance costs. We're going exactly the opposite way at the present time. Increased use of concrete to reduce the maintenance costs. Those of you who haven't heard the message yet, the national average metal beam barrier maintenance cost is 50 cents per linear foot per year. The national average concrete barrier maintenance is a penny per foot per year. If you have any reasonable idea what the highway agencies' problems are now money-wise, you understand very quickly why concrete is becoming terribly popular. It's economically feasible.

OPERATOR AND SAFETY PROBLEMS

James O'Day
Highway Safety Research Institute
The University of Michigan

JIM PLINE: Our next speaker is James O'Day, with the Highway Safety Research Institute at the University of Michigan. He's head of the Systems Analysis Division at that agency. He's been involved over the years in accident investigation, processing and analyzing accident data, has frequently written and presented papers on safety of large and small cars, and had a short tour down in Australia as a consultant to them on safety matters.

JIM O'DAY: As Don Woods said, one of the hardest things to do with this kind of problem is to describe distributions out of data that do not exist and that's what I'm going to try to do, too. The only joy in this is by the time the real data exist to prove that I'm wrong, most of you will have forgotten who said it. Listening to this morning's speakers, I'm not sure that safety matters much to anybody anyhow. We'll proceed from there.

Thousand pound cars just don't exist in the United States in quantities large enough to measure anything (in the present accident data) about their safety performance. Let's start with some data on vehicles that do exist and use some sort of a physical model to proceed from that into the future. I want to start by describing two relationships, one a sort of an empirically-derived relationship from accident data, and the other just a physical model that I think you'll all believe. First the empirical data.

Injury or fatality to occupants of a crashed car results from a variety of things that happen. Carl mentioned the 30G level as an important severity you don't want to exceed, but, many fatalities occur because of an interaction with some part of the body with some part of the vehicle at much less than 30G's. There are lots of things that happen to cause serious injuries and accidents. There have been a lot of crash severity measures tried over the years in accident investigation and in vehicle testing, vehicle design. Many of these correlate more or less well with the probability of occupant injury. Years ago, we used traveling speed because that was what police reported on their accident reports--we'd look at accidents and find out how many people survived or didn't survive for crashes that happened at a 30 mile an hour traveling speed or whatever. A severity estimate closely associated with traveling speed which was used in analysis was the barrier equivalent velocity or BEV. The barrier equivalent velocity would be the equivalent speed of hitting a barrier with the car in a frontal direction. We have also used measurements of the vehicle damage extent and developed a relationship between inches of crush and speed of impact. All of these quantities have been used to estimate crash severity.