CHAPTER 8 Small and Large Vehicles

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Special Considerations for Small Vehicles

An increased sensitivity of the small automobile to road surface discontinuities is indicated from accident data and increased probability of injury to the occupants of such vehicles. A recent study by Griffin (1) indicates that lighter-weight cars may be more likely to be involved in curb accidents than are heavier cars. In a study on tire defects, Campbell (2) presents data that suggest that small cars may be disadvantaged by roadway discontinuities and disturbances. In his article, Campbell demonstrates that accident-involved subcompact cars are far more apt to be cited for tire defects than are accident-involved large cars. Furthermore, this phenomenon is upheld when controlling simultaneously for vehicle age and driver age. Whether this phenomenon results from higher rates of rotation for smaller tires or from greater abuse suffered by smaller tires when striking ruts, potholes, edge drops, foreign objects, and so forth remains to be seen. Simply concluding that small vehicles are more sensitive to all surface problems does not appear to be warranted. In Chapters 3 and 4 (3,4) it was demonstrated by tests that a small vehicle could handle pothole traverses less effectively than a large car, but that it was no more sensitive to pavement edges than some larger vehicles.

Steward and Carroll (5) have noted that crash involvement rates for smaller cars are greater than for larger cars. Why this disparity in rates exists is not commented on. Perhaps smaller cars are driven by younger drivers, at higher speeds, or in different circumstances. Or perhaps roadway disturbances (e.g., inadequate friction) pose more severe problems for smaller cars than they do for larger cars.

A recent analysis by L.I. Griffin (unpublished data) suggests that smaller, lighter-weight cars may be more susceptible to skidding accidents than larger cars (see Figure 1). In this analysis single-vehicle accidents involving passenger cars of known curb weight were coded 1 if they resulted from skidding and 0 otherwise. Logistic regression procedures were then applied to estimate the influence of curb weight on the probability of an accident being classified as a skidding accident. A logistic regression equation of the following form was built:

$$Y = \exp(a + bX)/[1 + \exp(a + bX)] \quad (1)$$

where

Y = probability of an accident being coded as a skidding accident,
X = vehicle curb weight, and
a,b = regression coefficients.

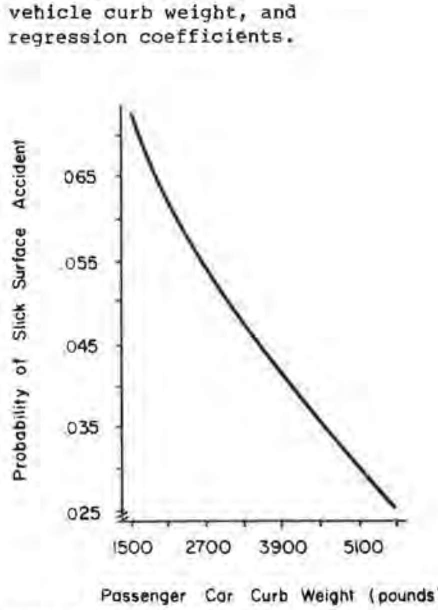

FIGURE 1 Probability of involvement in slick surface accidents as a function of passenger car weight.

The maximum likelihood estimates of a and b are $a = 2.17760701$ and $b = 0.00024691$. A chi-square test was carried out to determine if the two variables (X and Y) are independent. The resulting chi-square was 59.34 ($p < 0.0001$), which indicates they are not.

Whether the relationship depicted in Figure 1 results from the simple physical interaction of road surface characteristics and passenger car curb weight or other spurious factors that vary with vehicle weight (e.g., driver age, speed) will require further research. The fact that vehicle wheel base and track width are smaller with the lighter vehicles implies reduced directional stability, which provides a relatively direct explanation of the apparent susceptibility of these smaller vehicles to slick surface accidents.

Special Considerations for Large Vehicles

Thus far the geometry of the roadway surface has been discussed largely from the perspective of how it influences safety of passenger cars. In this section the attention turns to the larger vehicles used for commercial transportation. Commercial vehicles encompass the spectrum of vehicles used to transport goods, ranging from the two-axle medium truck with a gross vehicle weight of 15,000 lb to the heavy-class articulated tractor-trailer combinations that may have from 3 to 11 axles and may operate at gross combination weights of 72,000 to more than 150,000 lb. Likewise, the commercial vehicle class includes buses used for transporting passengers that fall in the midrange of the sizes just described. In total, commercial vehicles represent about 20 percent of the vehicles on the highway. Of these, approximately one-half are the common tractor-semitrailers, which are the primary focus in the following discussion.

Accidents with commercial vehicles risk injury or death not only to their own occupants but especially to other motorists. Because of their weight disparity with other vehicles on the road, occupants of other vehicles are more frequently killed in collisions with combination vehicles. The statistics are illustrated in Figure 2, which shows the distribution of fatalities in different types of vehicles, taken from the 1980 Fatal Accident Reporting System (FARS) data (6). In accidents between combination vehicles and passenger cars, 1,775 occupants of passenger cars were killed in contrast to 53 occupants of combination vehicles.

The same study (6) also provides some insight into the significance of roadway surface condition as a first factor contributing to truck-car accidents. Figure 3 shows that, among the 20 possible first contributing factors coded in a 1979 Pennsylvania study, the roadway condition was the sixth most important.

Because of their size and design, large commercial vehicles have characteristics that are uniquely different from passenger cars, which affects their sensitivity to roadway discontinuities. Those differences are seen in the roadway characteristics relating to the response to roughness discontinuities in the roadway and to tire-road friction coupling.

Discontinuities in the surface of a road that would fall in the classes of generalized roughness, potholes, edge drops, or other special features will affect commercial vehicles differently than passenger cars. Because of the larger tires used on these vehicles, the abrupt features are normally not as significant as an input to large vehicles. That is, a truck tire running through a pothole or over a curb edge, because of its size, is able to negotiate the feature with less disturbance to the vehicle. Such discontinuities impose a vertical and a longitudinal force on the wheel, the relative magnitude of which is inversely proportional to tire size. This relationship holds because trucks have larger tires that tend to smooth out the abrupt discontinuities, and they have more deflection distance available within the tire to absorb the disturbance.

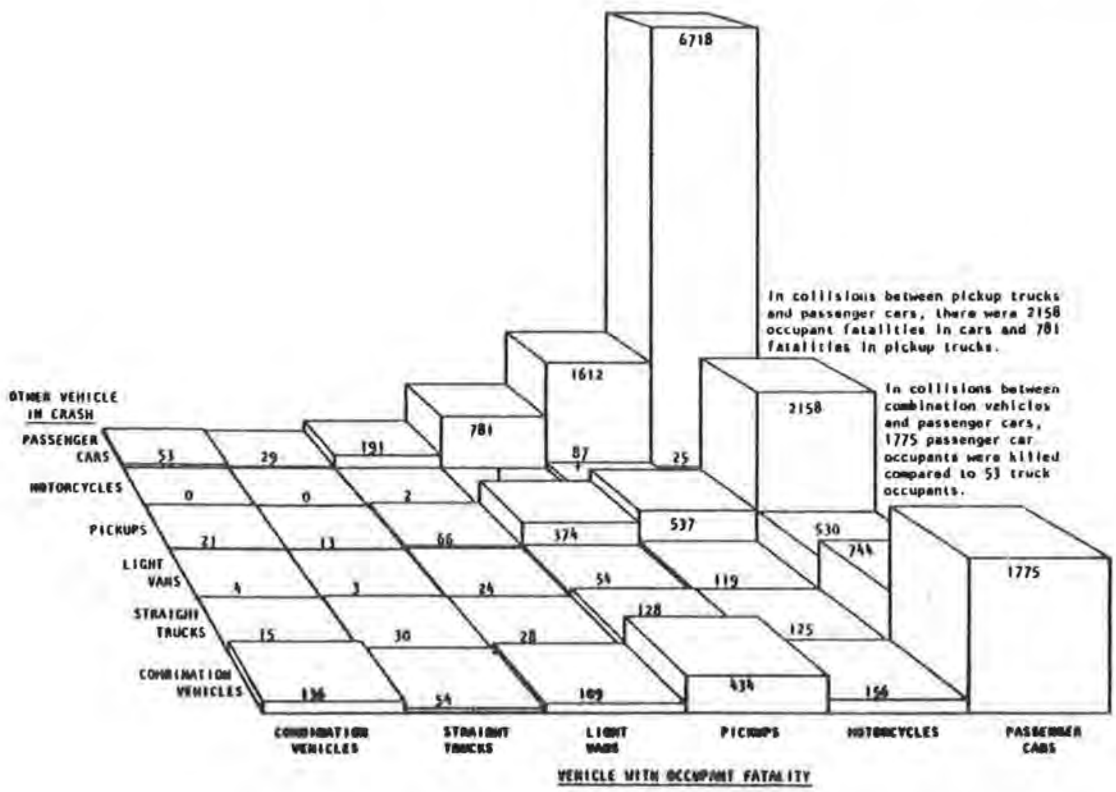

FIGURE 2 Occupant fatality distribution by mix of vehicles, U.S. two-vehicle fatal crashes in 1980 (N = 17,137).

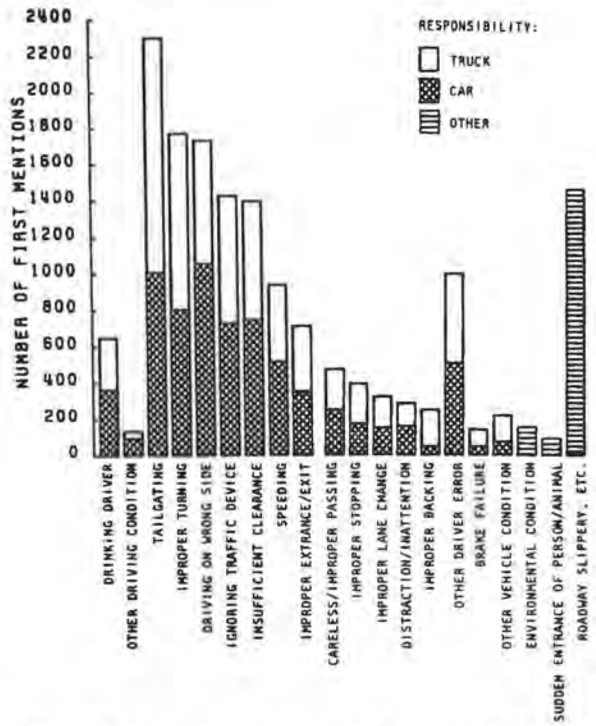

FIGURE 3 Responsible first contributing factors in 1979 two-vehicle truck-car crashes in Pennsylvania.

Counterbalancing the advantage gained from the larger size of truck tires is the reduced isolation provided by their typical suspension systems, stiffer springs, and higher tire pressures. In order to maintain appropriate vehicle positions over a broad range of load conditions, the more common suspension types must have a high effective stiffness. As a consequence, those disturbances imposed through the tire are more directly transmitted to the vehicle chassis.

No definitive research has been done to quantify the sensitivity of large vehicles to the more abrupt features in the nature of potholes, curbs, or pavement edge drops. From the knowledge of truck dynamic properties, it may be expected that certain types of these road features can create a greater vibration disturbance to trucks than to cars. In addition, there exists the concern that such road features may produce a steering disturbance, with potentially greater consequence to a truck. Yet until such research is performed, no conclusions can be proffered.

In the broader area of generalized roughness in roads, there has been some recent research to determine its influence on safety (7). It may be concluded from that study that truck vibration response to road roughness is qualitatively similar to passenger cars, albeit at a much higher level. It may be inferred that, on average, roads that appear rougher to cars are also rougher to trucks. Hence the effort to maintain roads to acceptable levels of roughness for passenger car use will, at the same time, keep them generally suitable for trucks. Although the vibration levels induced on trucks by road roughness are much higher than on passenger cars, that same study concludes from a polling of experts that there is no direct link to safety of operations.

Perhaps the one area of possible influence that has not been well addressed in the literature is the significance of special wavelengths of road roughness to which trucks may be sensitive. It is known among experienced truck drivers that certain long wave road undulations, as typified by pavement settlements in bridge approach areas, may be peculiarly difficult to negotiate with commercial vehicles, particularly tractor-semitrailers. These features tune to the low-frequency rigid-body bounce and pitch modes of these vehicles. Because the drivers are located near the extremities of the vehicle (far from the center of gravity), large displacement vertical and fore-aft motions can be imposed on the driver, thus complicating the task of maintaining control when negotiating these road features. There is anecdotal evidence that truck drivers have experienced control problems reflecting on safety due to these effects, but there has been no known effort to compile statistics quantifying the magnitude of this particular problem. Unfortunately, available accident data are not specific enough in their recorded detail to provide that answer.

In summary, it must be concluded that the knowledge is deficient to state with confidence which road features constitute peculiar safety problems for large vehicles. Relying on the general knowledge of such vehicles, however, points to the need to better understand certain long wavelength roughness qualities in roads as potentially unique problems for such vehicles.

Commercial vehicles achieve their greater load-carrying capacity not only by the use of more axles but also by the use of larger tires operated at higher inflation pressures. The higher road-tire contact stresses thus obtained are also cause for the use of tread rubber compounds that differ from those commonly used on passenger-car tires. Thus it is not surprising to find that truck tires exhibit traction qualities distinctively different from passenger-car tires. Quantitatively, truck tires exhibit lower peak tractive force coefficients of friction on a given surface (8), the sliding coefficient of friction is proportionately even lower (8,9), and truck tire traction qualities are more linear with load (10).

The traction differences of truck tires, either on dry or wet roads, do not appear to have a major safety significance because the vehicles' accident-avoidance capabilities are not as uniquely traction limited as with passenger cars. Intuitively, it can be hypothesized that commercial vehicle safety would be linked to emergency braking capability and to limited cornering capability.

Studies of the safety benefits accrued from higher performance airbrake systems (11), however, fail to demonstrate any benefit from improved stopping-distance performance. Thus it would be inferred that the nominal traction limits of current truck tires on the road are not significant to safety in braking situations. Although this conclusion has broad implications, it can be rationalized for some situations, but not others. On dry pavements truck braking capability is normally more limited by vehicle design than by road friction characteristics. On lightly wetted roads truck tire traction is not severely disparate from that of passenger-car tires, and in the case of heavy water accumulations, the higher contact pressures under truck tires undoubtedly result in greater resistance to hydroplaning, except possibly in the case of lightly loaded tires.

Ice- and snow-contaminated conditions are most critical for commercial vehicles (12). The more critical nature arises from several key differences: articulated vehicles have unique modes of instability (e.g., capability to jackknife), accidents are more severe because of greater size and mass, and

TABLE 1 Number of Tractor-Trailer and Doubles Accidents from 1980 FARS Data

Vehicle Weight (lbs)	Accident Type	Road Condition Dry	Wet	Snow	Ice
10,000-30,000	All Accidents	483	101	22	20
	Jackknife	49	24	11	5
	(Percent)	(10.1%)		(28.0%)	
30,000-50,000	All Accidents	448	84	16	17
	Jackknife	30	14	1	3
	(Percent)	(6.7%)		(15.4%)	
50,000-70,000	All Accidents	575	104	16	29
	Jackknife	42	15	7	4
	(Percent)	(7.3%)		(17.4%)	
70,000-90,000	All Accidents	756	100	17	24
	Jackknife	68	13	3	6
	(Percent)	(9.0%)		(15.6%)	

these vehicles are more prone to rollover, even in the absence of a collision.

The higher tire contact pressures that resist hydroplaning on wet roads can be a detriment on ice- or snow-covered roads. Except at extremely low temperatures, the low friction coupling on ice-covered roads is dominated by the water film developed on the surface caused by frictional heating (13) and the contact pressure of the tire. Inasmuch as truck tires have higher loads and contact pressures, the low friction level is likely to prevail over a much wider temperature range than occurs with passenger-car tires. The combination of all these factors is then cause for greater concern for the safe operation of large commercial vehicles on snow- and ice-covered roads.

The cornering performance limits of commercial vehicles are established by two predominant modes--rollover and yaw instability (13). Rollover, in and of itself, is not an accident-causation factor that is aggravated by deficient road surface conditions. The rollover limit has a first-order relationship to the ratio of center-of-gravity height to track width, thus making it specific to the vehicle. Road friction is only significant in the sense that its nominal level will determine whether rollover is possible while the vehicle remains on the road. That is, the rollover limits for many commercial vehicles are low enough that rollover (rather than simple spin-out) is possible with loss of control on dry roads, although not as certainly on wet roads. At the same time the risks of loss of control are also greater on wet roads. Of course, once a combination vehicle has left the road, the probability of rollover is greatly increased by roadside cross slopes and soft soil conditions.

The second limit mode--yaw instability--is a technical term describing the onset of jackknife with articulated vehicles or spin-out with straight trucks (13). By the nature of the way in which the load is carried, and the way in which the roll resistance is shared among axles on commercial vehicles, their turning performance is most often limited by loss of cornering force on the rear axles of a truck or tractor. When this occurs, spin-out follows, with a subsequent risk of rollover. The loss of cornering force is, in part, a function of the road surface and its friction level. In pure cornering maneuvers, the threshold of instability occurs at rather moderate slip conditions (3 to 5 degrees of slip angle), where the cornering force properties are much more dependent on the stiffness of the tire carcass than on the tire-road coefficient of friction. However, when braking is also combined with cornering, brake slip at the rear wheels will contribute to loss of cornering force and subsequent jackknife. Consequently, the potential for this type of accident is greatest when the vehicle is unloaded or when the tire-road coefficient of friction is low. The effect shows up in the accident statistics such as the 1980 FARS data for tractor-trailers and doubles (see Table 1). Taking the 10,000- to 30,000-lb weight as indicative of unloaded vehicles, and the 50,000- to 70,000-lb weight as typical of loaded vehicles, the statistics can be summarized as follows:

1. On dry pavements jackknife is involved in about 7 percent of all fatal accidents of loaded combination vehicles and about 10 percent of those for unloaded vehicles, and
2. On wet, snowy, or icy roads the jackknife involvement increases to nearly 17 percent for loaded vehicles and 28 percent for unloaded vehicles.

Thus from the standpoint of tire-road friction

FIGURE 4 Serious truck accident under wet weather conditions.

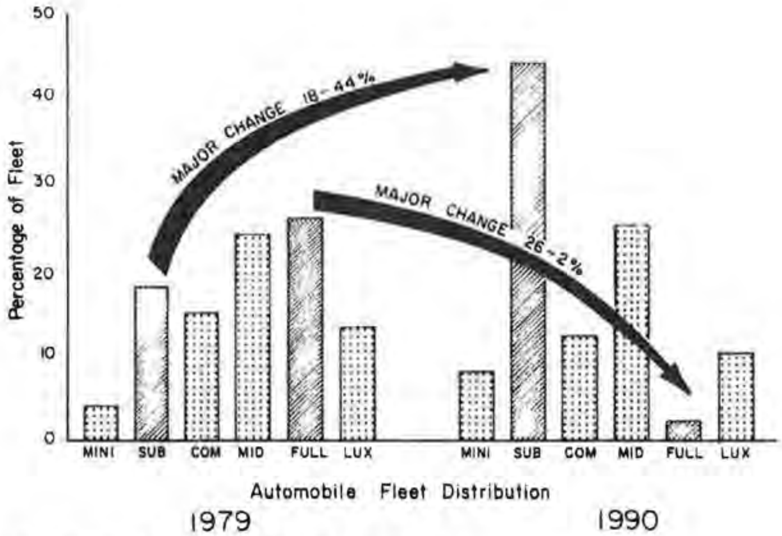

FIGURE 5 Shift in automobile size distribution.

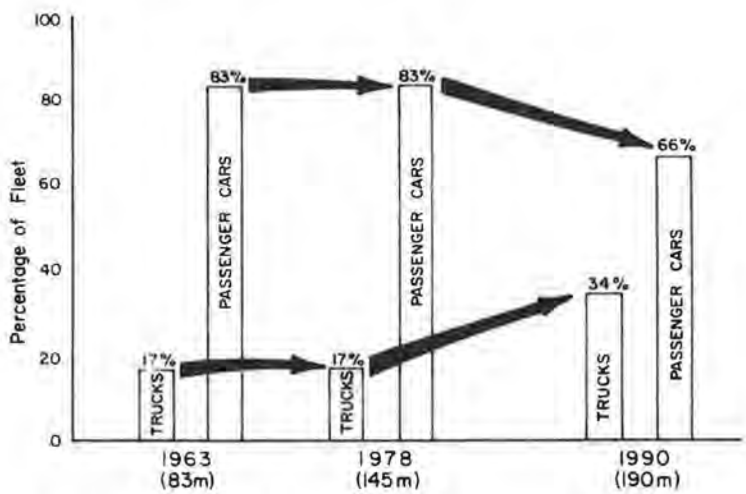

FIGURE 6 Shift in population distribution between stucks and passenger cars.

coupling, it is concluded that the safety performance of large commercial vehicles is uniquely critical on roads contaminated with water, ice, or snow. The threat to large vehicles under these conditions arises from the potential for loss of control, thus leading to more severe accidents; even at low speeds, jackknife or rollover accidents, like that shown in Figure 4, are possible.

The highway vehicle spectrum is changing rapidly. Figure 5, presented by C.V. Wootan, shows an estimate of shifts the automobile population will undergo by the year 1990 (note that these data are from an unpublished presentation, The Changing Vehicle Mix and Its Implications, given to the Texas Institute of Traffic Engineers in El Paso, February 1980). The small end of the spectrum, represented primarily by subcompacts, shows these vehicles becoming the dominant passenger automobile.

The way in which the large end of the spectrum is shifting is shown in Figure 6. Wootan suggests that trucks will make up 34 percent of the vehicle population by 1990. This segment of the vehicle population, including formidable 18-wheelers, double-bottoms, and even triple-bottoms, is increasing in number precipitously, and increasing in size and weight as fast as the technical, economic, and political climates will allow.

With these major changes occurring, which influence both the creation of road surface discontinuities and the sensitivity of vehicles to them, far more effort may be warranted to determine the interactions between vehicle size and the roadway surface problems that influence traffic accidents.

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