Highway Risks at Extreme Speeds

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IN 1961 there were 800 fatal injuries in highway accidents that didn't occur. They didn't occur because in 1956 automobile manufacturers began installing a new type of door lock on all U.S. cars. In certain accident circumstances where the old door locks failed to hold the door closed, the new door locks did the job. Consequently, instead of being thrown out of the car (with a high risk of a fatal injury), the occupant stayed inside (with a much lower risk of a fatal injury). From the scientific studies of the Automotive Crash Injury Research Program (ACIR) of Cornell University it is possible to make a reasonably accurate evaluation of the number of lives saved by introduction of the modified door lock (*1*). It is also possible to determine that the modified door locks were only about 33 percent effective. As a result, further modifications have been made in the door locks going into most U.S. cars. Eventually, it may be possible to prevent some 5,000 deaths on our highways each year by these seemingly minor changes in the design of a single item of hardware (*2*). If scientific knowledge gained in the past decade were fully utilized, the highway toll could probably be cut in half in the next 10 years (*3*).

As of now, the main task is to apply the scientific findings to the design and construction of U.S. cars. The final decisions as to what safety hardware goes into the assembly line are made by the automobile manufacturers. Safety is not the only consideration since the product must compete for consumer acceptance. Sometimes, as with door locks, these decisions have improved the safety of the product. Other design decisions have tended to swell the highway toll.

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Delay in translating new scientific knowledge about highway accidents into hardware contributes to 15,000 unnecessary deaths on our highways each year. Extreme speeds have been especially costly in deaths, disabilities, and human suffering. Yet the scientific study of highway accidents associated with extreme speeds could yield results just as positive as those that came from the study of door locks.

Extreme-Speed Accidents

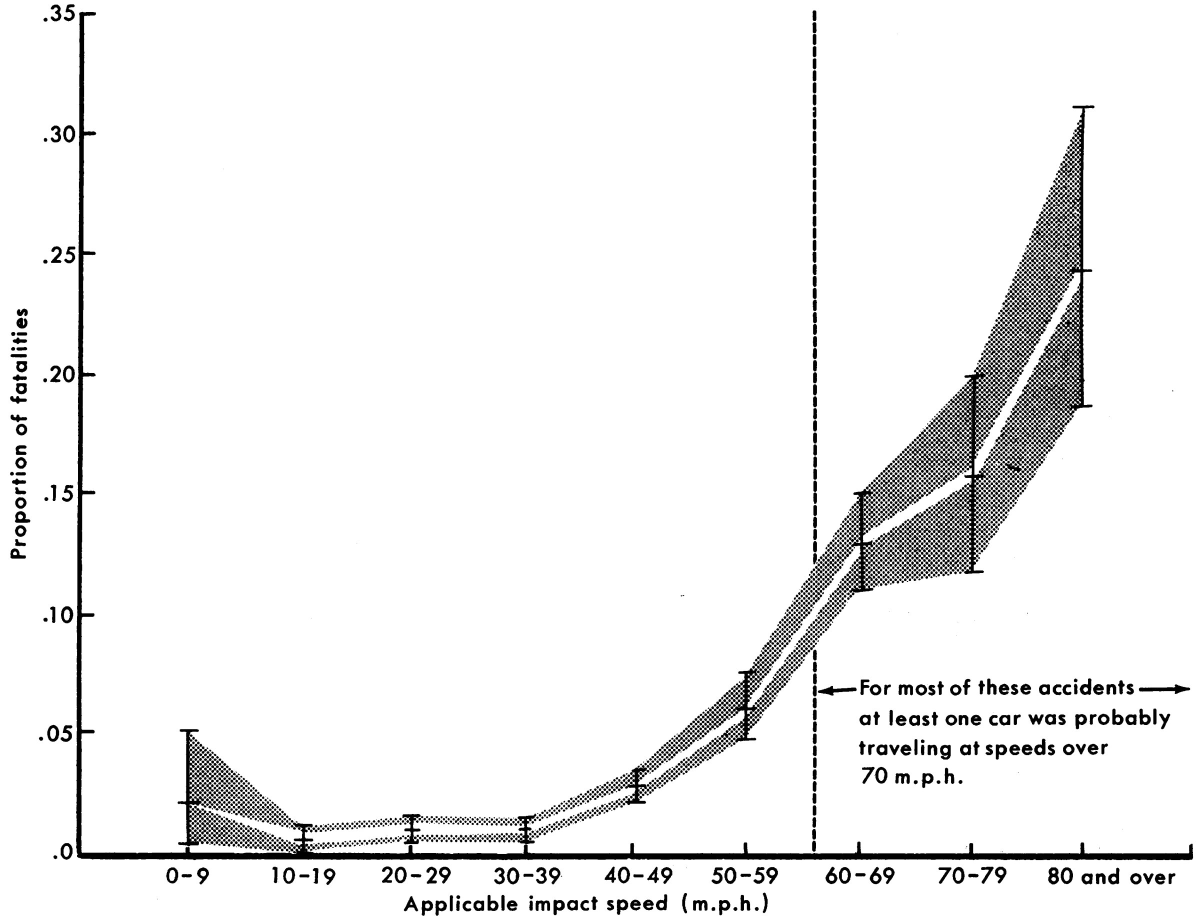
The hard core of the speed problem is the accident where at least one vehicle is traveling more than 70 miles per hour (that is, extreme-speed accidents). There are several main reasons why. With existing hardware, such as safety belts and padded instrument panels, occupants of a vehicle can be protected fairly well against fatal injury in accidents at speeds up to about 45 miles per hour. Unfortunately such hardware is not yet in wide use. There are a few special situations, such as accidents where one car invades the passenger compartment of another car (broadside accidents), which are hazardous even at low speeds. However, in a majority of low-speed circumstances, the occupants can be protected. In the intermediate range, 45 to 70 miles per hour, protection is poorer, but further developments in safety hardware may reduce the risk of injury in this range. In accidents at extreme speeds, however, safety hardware is ineffective because the passenger compartment tends to become "uninhabitable." At speeds up to 70 miles per hour (except in situations such as broadside collisions) the passenger compartment usually holds together.

Extreme speeds account for a sizable portion of all highway fatalities. In an ACIR sample of 14,198 automobile occupants involved in in-

jury-producing accidents on rural highways, there were 590 fatalities. Of these fatalities, 291, or about half, occurred in extreme-speed accidents. Two separate risks account for the heavy toll of extreme speed. First, a car moving at extreme speeds has a greater chance of getting into an injury-producing accident than a car moving at lower speeds. Second, if an accident occurs the occupants have a greater chance of being killed. The facts concerning this second risk are shown in figure 1. The risk of fatality rises sharply as the speeds enter the extreme range. For technical reasons, figure 1 uses the "applicable impact speed." Traveling speeds tend to be about 10 miles per hour higher than impact speeds, since there is usually some braking and evasive maneuvering before collision. The risk of fatality is doubled or tripled when the speed moves beyond the "legal" range (50–59 miles per hour). The shaded area indicates the confidence intervals on the estimated risks.

The risk of meeting with an accident cannot be precisely estimated from the ACIR data. The difficulty is that cars enter the sample only if they are involved in injury-producing accidents. The speeds of the other cars in the traffic streams are not known. The ACIR data show that the 14 percent of the occupants in extreme-speed accidents accounted for half of the deaths in the sample. Other considerations suggest that the proportion of occupants in cars traveling in the extreme-speed range may be about one-third of the 14 percent figure, or

Figure 1. Risks of fatality for occupants in rural injury-producing accidents, by applicable impact speeds



NOTE: Impact speeds tend to be about 10 mph lower than traveling speeds because of some braking before impact.

about 5 percent. It is inferred that the risk of accident is at least double when a car moves into the extreme-speed range. Possibly it is 3 or 4 times as great as the risk at moderate speeds.

The risk of fatality is roughly the product of two preceding risks. Hence, the extreme speed multiplies risk of death at least by a factor of 4. This raises the question: If traffic can move with relative safety at, say, 60 miles per hour, why should increasing the speed by 20 or 30 percent produce such a drastic increase in the risks?

How Accidents Happen

The stock answer of safety experts and editorial writers has been that "crazy" drivers are to blame. Among the many studies of this question, there is little or no evidence to indicate that drivers who use the extreme-speed range are any "crazier" than other drivers. In any event, there are no psychological tests which can be given to a group of drivers to identify those drivers who will have accidents in the next year.

In the search for obscure personality traits or motives to account for highway accidents, a simple and straightforward explanation has been overlooked: The driver behaves normally but the circumstances are such that normal behavior invites serious trouble. To see this point it is necessary to consider the driver as part of a larger system, a system that also includes the vehicle and the highway environment. It is the interactions or interrelationships of the components of the system rather than the isolated components that govern the events of an accident at extreme speeds.

Suppose a typical driver, a middle-aged male, steers a standard, medium-priced car down a straight stretch of a two-lane rural highway. In what follows, the motives or personality traits of this driver will be much less important than his driving habits. Like most Americans, this driver spends most of his time in an urbanized environment rather than on the open road. In the course of his day-to-day driving, mostly at low speeds, he has acquired some deeply ingrained habits. Judging by aircraft accident studies, it may be predicted that in an emergency situation he will revert to these well-established habits.

Suppose that the car is going 40 miles per hour and that, as it tops a slight rise, the driver sees some debris in the road ahead. To avoid the debris the driver executes a familiar evasive maneuver that carries him into the left lane. Since the surface and pitch of the rural highway is different from the familiar city streets, the driver finds himself heading for the shoulder. At this point he automatically begins a corrective maneuver which holds the car on the road and allows him to swing back into his lane and proceed on his way. The driver has acted normally, the car has acted normally, and while the highway environment presented a hazard, such hazards are a normal feature of the environment. Complete absence of such hazards would be abnormal.

Now suppose the car was going 80 miles per hour. This immediately puts heavy time pressure on the driver, but let us assume that he does not panic and that he follows his usual driving habits. The high-speed evasive maneuver brings into play high accelerative forces (high g's). Doubling the speed does not merely double these forces; it results in a fourfold increase. This elementary law of physics plays an important part in the subsequent events.

High-g forces have a critical but rarely appreciated effect on the handling characteristics of the car. For example, in the familiar low-g situation the standard U.S. car has a definite understeer. This point can best be understood by imagining that the car is being driven around a circular test track. With neutral steer, there is a position of the steering wheel that would allow the driver to circle the track without moving the wheel from this neutral position. With understeer, if the driver had turned the wheel to the neutral position, he would have to turn a little further to hold the car on the road. With oversteer, if the driver turned to the neutral position he would have to reverse turning direction to hold the car on the road. Nearly all engineers favor understeer over oversteer. However, a driver can develop habits which will enable him to manage the car satisfactorily even if it oversteers (though the habits would be somewhat opposite from those for understeer). The crucial point is this: As the accelerative forces increase, the standard under-

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steer car changes its handling characteristics in the direction of oversteer (*3*).

Manageability

What is the effect of a change in steering characteristics of a car in the high-g evasive maneuver? The steering habits appropriate to the familiar steering characteristics of the vehicle will no longer hold the vehicle on course. Moreover, the habits which come into play to bring the car back on course will no longer achieve their goal. The driver is gripping the wheel of a car which for no apparent reason has suddenly become unmanageable. Moreover, this happens at the worst possible time, in the middle of an evasive maneuver that is difficult at best. The interaction of the driver, car, and highway has now produced a highly hazardous situation.

As the driver struggles with the controls, features of his car that provided comfort or even safety at moderate speeds now betray him. At moderate speeds the soft suspension system of the car nicely smooths out bumps and jolts, but it is a serious handicap in high-g maneuvers. As road-racing experience has shown (*4*), at this critical point the driver needs the "feel of the road." But the comfortable seats, soundproofing, power brakes, steering, and other modern hardware screen out the sounds and vibrations that would warn the driver of an impending skid. To put it bluntly: a standard U.S. car has a motor which will put the car into the extreme-speed range with ease. The rest of the car is grossly unsuitable for extreme-speed maneuvers.

There is a close though not quite exact analogy between what happens in the extreme-speed range and what happens when a car is driven in powdery snow. As long as a car is driven at a fairly constant speed without sharp turns, the car performs in snow much as it would on a dry highway. However, in sharp turns or abrupt braking where stronger accelerative forces come into play the car becomes unmanageable, unless the driver is used to driving in snow. Because snow reduces the coefficients of tire friction, abnormal performance occurs even at low g's. On a dry highway, the changes require much higher g forces. However, extreme speed and snow are similar in this respect: The car does not go where the driver points it.

Is there any factual evidence that in the extreme-speed range U.S. cars become unmanageable for the average driver? Here is one significant fact from the ACIR data: At high speeds, one of every three cars in the sample is in a "primary rollover" accident, a type of accident indicative of loss of control.

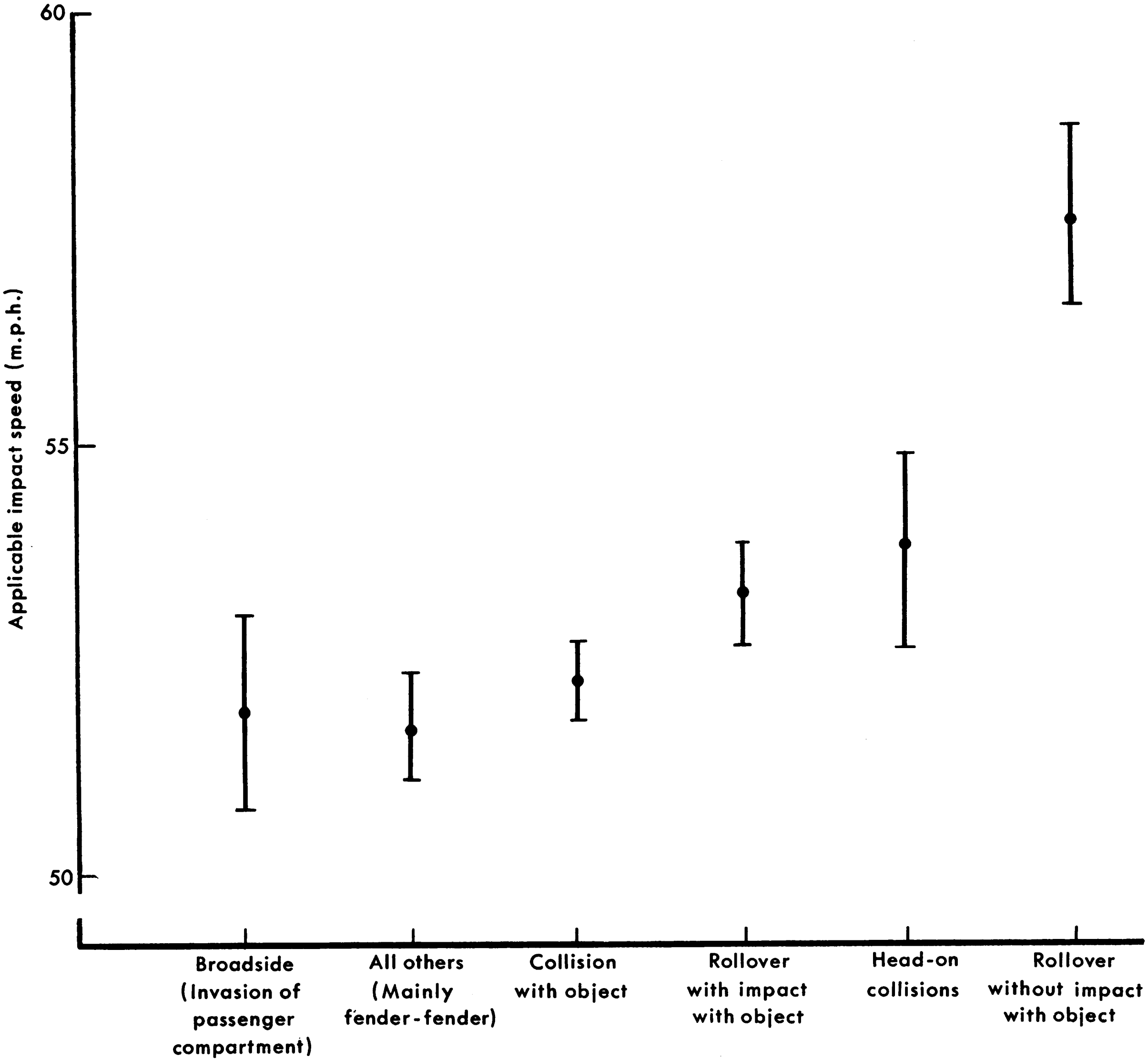
What about the track tests that automobile manufacturers run on their new models? Wouldn't the unmanageability show up there? The answer to this is suggested by what happened when manufacturers attempted rollover crash tests on their cars to check the performance of safety hardware. Although, as the ACIR data indicate, ordinary drivers apparently have no trouble getting into rollover accidents, the test drivers had a hard time getting the cars to roll. This might seem inexplicable, until the role of driver habits is recalled. Unmanageability refers to the system. In a "new car–test driver–test track" system the cars are manageable. Given a system of "usual car, average driver, and ordinary highway" the cars are not manageable in the extreme-speed range.

By using the ACIR data that were previously used to show the relationship between the applicable impact speed and the risk of fatal injury, it is possible to test the hypothesis of unmanageability at extreme speeds against the facts derived from investigation of actual highway accidents. For reasons explained previously, the speed distribution in the traffic streams in the areas sampled cannot be determined from the ACIR data. However, it is plausible to assume that for speeds of more than 40 miles per hour the distribution can be represented by an exponential decay distribution. The risk of meeting with an accident if the car is moving at a given speed would be expected to increase with increasing speed. This risk would be described algebraically by a positive exponential. However, if the unmanageability hypothesis plays an important role in the accident picture, the rate at which the risk increased would be different for different accident configurations. In sideswipe and fender-fender accidents between two cars, steering characteristics would be only one of the major factors. On the other

hand, in a configuration such as a "pure" rollover (rollover without impact with an object) the steering characteristics would be the dominant factor. Hence, we expect the rate at which the risk increased to be highest in this configuration.

When these verbal statements are put in mathematical terms and standard statistical procedures (maximum likelihood) are used to estimate the rate at which the risk increases in a given accident configuration, it develops that the estimates depend on an easily calculated quantity. This quantity is the arithmetic mean of the speeds in accidents where the applicable impact speed is more than 40 miles per hour. It is therefore simple to test the unmanageability hypothesis against the accident facts. If the averages in the different accident configurations are all the same or if the ordering by the averages bears little relationship to the role of steering in various accident configurations, the unmanageability hypothesis would be rejected. Conversely, if ordering the configurations by the arithmetic means corresponds to the relative importance of steering in various types of accidents, this would support the unmanageability hypothesis. Furthermore, the exponential assumptions mentioned earlier can

Figure 2. Average speeds and confidence intervals for six accident configurations



be checked graphically, and they appear to be a fair first approximation.

The results of this test are shown in figure 2 in the form of confidence intervals. These intervals are easy to interpret. If the confidence intervals in two accident configurations overlap, then the rates at which the risk of accident increases with speed are probably quite similar in the two types of accidents. On the other hand, if the intervals do not overlap, this indicates a difference in the rates in the two types of accidents. Figure 2 shows that rates in the six accident configurations are clearly different, and that the differences are about what would be expected if the unmanageability hypothesis is an important factor in the accident picture. To nail down the hypothesis we would really need a series of intensive investigations of actual highway accidents which would gather more direct evidence of unmanageability (for example, from an analysis of the actual track of the evasive and corrective maneuvers). The data in figure 2 and other information on steering characteristics cited previously should encourage investigators to seek such direct evidence.

Solving the Speed Problem

Assuming the validity of the hypothesis that unmanageability at extreme speeds is a major highway hazard, what technical improvements are indicated? At extreme speeds, our current automobiles in the hands of average drivers become unmanageable in evasive or corrective maneuvers. While improvements can be made in the highway environment, it is clear that various road hazards will continue, on occasion, to demand evasive maneuvers. While driver behavior can, in theory, be modified by education or punitive measures, drivers can be expected nevertheless to persist in familiar driving habits. If it is easy and comfortable to drive the car at extreme speeds, some drivers will use this range. These drivers will find their cars unmanageable in evasive maneuvers and will continue to have accidents. It is hardly realistic to suppose that more education or more speed laws will have much effect on them. The one component of the system that is relatively easy to modify is the car.

There are several different approaches to redesign of the vehicle to reduce the toll of extreme speeds. One would be a governor to prevent sustained travel at extreme speeds. Another is to control engine specifications, the approach used in road racing whenever the unmanageability of the vehicles becomes obvious. Yet another way would be to engineer the entire car (not merely the motor) for driving in the extreme-speed range. A drawback to this approach is that the car would have to be very uncomfortable at low speeds and would be hard to sell. The main point here is that manufacturers are quite capable of redesigning cars to enhance safety, possibly along some line that hasn't been mentioned. The real task is to develop a strong incentive to produce manageable cars which have public acceptance.

The key word here is "manageability." This term is meant to apply to an actual system: the driving population in the United States, the cars that are on the road, and the present highway system. This is a somewhat different concept of the term than is conventional in automotive engineering. For example at high g's a vehicle, in theory, becomes "absolutely unmanageable" when the steering wheel angle has no effect on the course of the vehicle. According to current theory (*3*) this state could be reached by reversing the manufacturers' instructions on tire inflation for certain rear-engine compacts and setting certain other conditions, such as shortest possible turning radius. Although "absolute unmanageability" could presumably occur at speeds about 65 miles per hour, I know of no actual demonstration of this phenomenon either on the test track or on the highway. However, long before a vehicle became absolutely unmanageable it would become unmanageable in the hands of an ordinary driver.

As an experiment, one major State legislature might require that all makes and models manufactured after a given date, in order to be eligible for licensing, meet certain standards of manageability. With the pattern of aircraft regulations as a model, the State could require that all highway collisions resulting in a fatality be reported within 48 hours to a roadworthiness commission, staffed to investigate the circumstances. If evidence of unmanageability

is established, after specified hearings and appeals, the commission would be empowered to designate the unmanageable model as ineligible for licensing. The mere establishment of such a commission might be sufficient incentive to intensify the study of manageability and to encourage the design, manufacture, and sale of manageable cars.

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Twelve regional technical report centers were established in libraries and universities throughout the country on July 1, 1962, to receive and disseminate unclassified results of federally sponsored research and development.

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The new system of report centers was set up by the Office of Science Information Service of the National Science Foundation and the Office of Technical Services of the Department of Commerce with cooperation from the agencies which are contributing material. The Office of Technical Services is managing and coordinating operation of the system.

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