Institute of Transport Economics
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Summary

Road safety effects of vehicles crashworthiness, weight, and compatibility

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This report presents results of literature reviews of the effects of vehicles crashworthiness, weight, and compatibility on crash severity, as well as effects of electric vehicles on crashes and crash severity. Crashworthiness is the degree to which vehicles protect occupants from (severe) injuries in crashes. However, vehicles crashworthiness can also affect injuries among crash partners. Empirical studies have investigated the relationship between crash test results (in programs such as Euro NCAP) and injury severity in crashes, changes of vehicles crashworthiness over time and differences between different types of vehicles. The relationship between vehicles' weight and injury severity, both among own occupants and crash partners, has been investigated as well. Crash compatibility describes the degree to which vehicles protect both own occupants and crash partners in collisions. Some studies have estimated potential effects of changing the composition of the vehicle fleet with respect to types of vehicles or vehicle weights on the total number of killed or seriously injured. Effects of crashworthiness, weight and compatibility for electric vehicles are described in an own chapter which also addresses the effects of electric vehicles on crash risk.

The main focus in this report is on empirical studies of real world crashes. As far as possible, results are summarized with meta-analysis. Most results refer to light vehicles, i.e. passenger cars, sports utility vehicles (SUV), pickups, and vans.

The report is a part of the continuous updating of the Handbook of Road Safety Measures (Elvik et al., 2009). Short versions of all parts of the report are published in Norwegian online at http://tsh.toi.no/.

Crashworthiness

Vehicles' crashworthiness refers to the protection of (the own vehicle's) occupants in the event of a crash. Injury risk among crash partners may be affected as well. Empirical studies of results in crash tests, general changes of vehicles crashworthiness over time, and effects of vehicles' age are summarized in the following.

Crash test results

The aim of new car assessment programs (such as Euro NCAP) is to provide consumer information (in order to increase the sale of safer cars) and incentives for manufacturers to produce safer cars. Traditionally, new car assessment programs focus mainly on crash tests as indicators of crashworthiness. However, aspects of active safety (crash avoidance) are increasingly included in such programs.

Most studies of the relationship between crash test results and real world crash injuries are from the US (US NCAP, IIHS ratings), and some studies are from Europe (Euro NCAP) and Australia (ANCAP). In summary, the results indicate that better crash test results imply about 5% reduced injury severity. The results are however highly heterogeneous and far from all studies found monotonous relationship between crash test results and injury severity.

General improvements over time

The risk of being killed or seriously injured in a car (given the car is involved in a crash) has decreased for crash of later model years, on average by 4.2% per year. This is mainly due to improved crashworthiness. Increased weight has contributed as well. The combined injury risk for own car occupants and collision partners has been found to decrease for cars of later model years. The relationship between model year and injury risk among collision partners has been investigated in only few studies with contradictory results.

None of the studies indicates that the improvement of crashworthiness over time has started to slow down. Although there are limits for the survivability of serious crashes, studies of racing cars show that it is theoretically possible to construct cars in which even crashes at very high speeds can be survived.

Types of light vehicles

Injury risk for own car occupants has consistently been found to decrease with the vehicle's size. Injury risk in collisions is:

- Lower in larger vehicles
- Lower in 4WD cars than in other cars (probably due to size and weight differences)
- Lower in SUVs and pickups than in passenger cars (due to differences in both weight and geometry)
- Lower in heavy trucks and buses than in light vehicles
- The risk in sports cars is in between the risk in small and large passenger cars.

In single vehicle crashes the risk of serious injuries is larger in SUVs and pickups than in passenger cars. These differences are however likely to decrease over time as electronic stability control (ESC) gets more common on these vehicles.

Injury risk for crash partners has been found to increase with the own vehicle's size. Larger passenger cars impose higher risk to crash partners than smaller cars, and SUV and pickups impose higher risk than passenger cars. The differences between passenger cars and SUVs/pickups have decreased over time, partly because of increased compatibility requirements to SUVs and pickups. Heavy trucks and buses impose higher risk to crash partners than light vehicles.

The relationships that have been found between type of vehicle and overall injury risk (for own occupants and collision partners) are somewhat inconsistent between studies. The opposing effects of vehicles crashworthiness and aggressivity (the risk imposed on crash partners) may partly outweigh each other. However, most studies indicate that overall injury risk is somewhat higher for SUVs and pickups than for passenger cars.

Cars' age

Injury risk for own vehicle occupants has been found to be higher in older cars than in newer cars (when controlling for the cars' model year). On average, serious injury risk increases by 2.3% per year.

Weight

Heavier vehicles provide better protection for their occupants than lighter vehicles. For light vehicles, empirical studies show that increasing weight by 100 kg reduces fatality risk by 7.5% on average in collisions with other light vehicles. The relationship between weight and injury risk is stronger for more serious injuries than for slighter injuries, and has decreased over time. The latter is probably due to general improvements of vehicles' crashworthiness, as well as improved compatibility.

Weight differences between the own vehicle's and crash partner's weight affect injury severity as well. The larger the difference in weight, the larger is also the difference in injury severity. However, in heavier vehicles, the weight of a collision partner affects own injury risk less than in lighter vehicles.

Injury risk among collision partners has been found to increase with the own vehicle's weight. Increasing the own vehicle's weight by 100 kg increases fatality risk among collision partners by 6.6% on average.

Overall injury risk in collisions (for own occupants and collision partners) has been found to decrease with the vehicle's weight. However, the relationship between weight and overall injury risk has decreased over time. In collisions between vehicles of equal weight, increasing the weight of each vehicle by 100 kg has been found to reduce the total number of injuries by 3.7% on average. While this result is based on older studies, a more recent study showed that decreasing average weight in the vehicle fleet would reduce the total number of injuries and fatalities. Results from older studies on the effects of changing the weight distribution in the vehicle fleet are inconsistent.

Crash compatibility

Crash compatibility refers to the degree to which vehicles protect their own occupants in combination with the risk the vehicle imposes on collision partners. Compatibility depends on the vehicles geometric properties, weight, and stiffness, amongst other things. In order to maximize compatibility, the impact points on both vehicles in a collision have to be on energy absorbing structures.

Most studies of vehicles crashworthiness and aggressivity find a negative relationship between these two properties, i.e. better protection for the own vehicle's occupants comes about with higher injury risk for collision partners.

Increased compatibility requirements to SUVs and pickups in USA have been found to reduce injury risk for collision partners by 16% on average. The compatibility between SUVs/pickups and passenger cars depends mainly on the height of the vehicles' front structures and to a lesser degree on the use of energy absorbing materials.

«Arms race»: The total number of injuries and fatalities may increase if all drivers choose those vehicles that are safest for themselves because such vehicles for the most part are more aggressive. In order to minimize the total number of injuries and fatalities, all drivers have to choose vehicles that provide a minimum of total injuries/fatalities in crashes. Such vehicles are not necessarily those that will provide maximum safety to their own occupants in crashes with all types of occupants. Thus, the car choice of individual drivers resembles a «prisoners dilemma» in which the outcome of one's own choice depends on the choice of another person.

Protection of pedestrians and cyclists – car type: The risk of being killed or seriously injured is at least 50% higher for pedestrians and cyclists hit by a SUV or pickup, than for pedestrians and cyclists hit by a passenger car.

Protection of pedestrians and cyclists – NCAP pedestrian: Cars with better results for pedestrian protection in the test program Euro NCAP impose lower risk to pedestrians and cyclists than cars with poor results. Results from empirical studies are however not generalizable because of changes of test criteria over time.

Protection of pedestrians and cyclists – Pedestrian airbag and pop-up hood: These measures were found to reduce head injuries among pedestrians and cyclists hit by a car by about one third. However, pop-up hoods may change crash dynamics, resulting in more severe injuries from secondary contact to the ground.

Bull bars: Bull bars increase injury risk for collision partners, especially for pedestrians and cyclists hit by the car. However, the effects depend on the characteristics of the cars front (without bull bar) and the degree to which the bull bar consists of energy absorbing materials.

Electric vehicles

Crashworthiness: Electric vehicles have on average somewhat lower scores in Euro NCAP crash tests, compared to other cars in the same categories, and fewer electric vehicles have a total score of five stars. Hybrid vehicles have on average somewhat better test results than other cars.

Weight: Electric vehicles are on average about 10-25% heavier than cars with combustion engines within the same categories. Heavier cars have in other studies been found to provide better protection to own car occupants and to increase injury risk among collision partners.

Electric vehicles and vulnerable road users: Compared to cars with internal combustion engines, electric vehicles are more often involved in collisions with pedestrians and cyclists, especially on roads with low speed limits and at intersections. The difference in crash involvement may be due to the fact that electric vehicles make less noise than most other vehicles at low speed. However, electric vehicles also drive more in areas with many pedestrians, cyclists, and intersections, than other cars.

Fire safety: Batteries in electric vehicles imply potential fire safety problems, but no empirical studies were found that have investigated the fire safety of electric vehicles in real world crashes.