Side impact test proposals and the real world problem

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Side Impact Test Proposals and the Real World Problem.

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SYNOPSIS The two proposed mobile barrier tests for side impact are compared with real-world collisions. The tests are shown to reproduce serious injury collisions better than fatal collisions.

1 INTRODUCTION

The major objective of accident research for the last decade has been to find ways of reducing the levels of injuries sustained in side impacts to cars. The process commenced with studies of real world collisions to establish the necessary parameters for future legislative requirements. Experimental work followed to design test methods that would simulate side collisions and to design dummies that were able to discriminate between successful and unsuccessful car designs. Most recently this research and development has come to fruition with the publication in 1988 of an Advanced Notice of Proposed Rulemaking\textsuperscript{1} by the US National Highway and Traffic Safety Administration (NHTSA). The European Experimental Vehicle committee (EEVC) has also published its proposals for side impact legislation\textsuperscript{2}.

Both the European and the US proposals use a mobile deformable barrier to simulate a side collision with another car. The European test employs a barrier that represents the average European car in mass, stiffness, width, and height. It has an impact velocity of 50 kph in a perpendicular direction. The US test barrier represents the median US car mass, width and height but has a stiffness more like that of a light truck. It has an impact velocity of 54 kph coming from a 2 o'clock direction. Each test proposes a dummy that would measure the likelihood of injuries. The EEVC dummy, known as Eurosid, measures the likelihood of head, chest, abdomen and pelvis injuries separately. The US dummy, known as DOTSID, records measurements that are assumed to correspond to torso and pelvis injury. The EEVC test seats
a restrained dummy in the front of the struck side of the car while the US test seats two unrestrained dummies in the front and the rear on the struck side.

The objective of this paper is to examine how each of these sets of test proposals relate to real world side collisions and to appraise its likely effectiveness by estimating the numbers of car occupants who are in similar impacts.

1.1 Accident data

The Cooperative Crash Injury Study has been examining real-world car accidents in the UK for a number of years to determine the causes of occupant injuries and the influence of car design. The sampling and data collection procedures have been described elsewhere. The vehicles chosen for this analysis have all been involved in side impacts with a direction of force between 1 and 5 o’clock or between 7 and 11 o’clock. The data presented have all been weighted according to the sampling fraction so the results are representative of the local population. In the following analysis fatally injured occupants are defined as those who die within 30 days of the accident; those seriously injured have a maximum AIS of at least 3 but do not die within 30 days of the accident. Slightly injured occupants are the remaining occupants with injuries of some sort. An overview of this database has been published previously.

2 IMPACT CONFIGURATIONS

A primary characteristic of both test procedures is the impact of the barrier at a point on the car side adjacent to the dummy. The EEVC test centres the barrier on the R-point whereas the NHTSA barrier has its most forward impact point 94cm in front of the wheelbase centre.

The two test impact configurations involve dummies that are struck by the intruding car side structure. This side structure can be supported by the face of the impacting barrier so the effective stiffness becomes greater than that of the car side alone. This will only occur when the outer door panel is deformed to touch the inner panel. Occupants seated in positions where this may occur are classified here as being ‘potentially supported’. In the real-world car occupants may also be seated on the struck side and either be in front or behind the area directly struck by the bullet object but still
strike an intruding car side. These were classified as striking an unsupported car side. Additionally they may contact an undamaged car side and be classified as having a non-intruding contact or they may be seated on the non-struck side of the car. These definitions are shown in Figure 1 and the distribution of the occupants in the accident population is shown in Table 1.

Figure 1 Classification of intruding contacts
The accident data revealed that 723 (25%) of the 2922 occupants of all severities of injury experienced supported intrusion patterns similar to the test conditions. 108 (44%) of the seriously injured occupants and 51 (55%) of those who died were also in cars with equivalent intrusion patterns to the test. It was not possible to discriminate between the incidence of the precise impact locations of the two tests but both simulate the intrusion patterns most frequently observed amongst the seriously and fatally injured occupants. The EEVC barrier face has a central section that is stiffer than the outer sections to simulate the engine stiffness of bullet cars. Experimental collisions employing the barrier have suggested that this results in greater deformation of the central part of the door. Any contact from an adjacent occupant is therefore likely to be supported by the stiffer barrier face. The NHTSA barrier however has a constant stiffness across the barrier face. It tends to result in a constant deformation of the target car side structure that preserves the distance between the two door skins. There is therefore some potential ride-down space for an adjacent occupant. A further investigation of real-world accident data is required to examine the deformation patterns occurring in car to car side collisions and the effect.

Restricted occupants seated on the non-struck side of the car experienced quite different intrusion patterns. If restrained they rarely contacted an intruding car side. The changes in car design following adoption of either of the proposed test procedures will do little to reduce the injuries of these occupants. 48 (19%) of the seriously injured occupants are restrained on the non-struck side of the car as are 19 (20%) of the fatally
injured occupants.

Of the 30 fatal non-struck side occupants 14 (47%) were in impacts so severe that the intrusion extended into the non-struck side seat area and a further 6 (20%) were in cars that intruded above 45 cm but not as far as their own seat. Alternative methods of occupant protection such as improved seat belt systems or passive restraints for side impacts might be considered to reduce the injuries of the remaining 10 fatal non-struck side occupants. Such measures might also aid 28 (42%) of the 67 non-fatal seriously injured occupants seated on the non-struck side with low levels of intrusion to the vehicle.

The remaining 935 (32%) occupants are those seated on the struck side either with no intrusion or with unsupported intrusion or unrestrained non-struck side occupants. The test proposals will have some effect on their injuries but any reductions may not be as great as for struck side occupants with supported intrusion.

2.1 Direction of force

The EEVC proposals assume the test vehicle is stationary and apply loads from a perpendicular direction. The barrier described in the proposed US regulation however has a cranked motion to simulate a forward trajectory of the test car and loads are applied from a direction of 27 degrees forward of perpendicular. The real world data reveals that 36% of struck side occupants in side impacts are in cars with a purely perpendicular direction of force, while 41% have a force vector 30 degrees forward. Table 2 shows the clock directions of force for occupants with each level of injury.
Table 2  Direction of principal force for all struck side occupants.

<table>
<thead>
<tr>
<th>Clock of force</th>
<th>Fatal</th>
<th>Slight &amp; Serious uninjured</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 11</td>
<td>10(14%)</td>
<td>28(14%)</td>
<td>147(9%)</td>
</tr>
<tr>
<td>2 &amp; 10</td>
<td>39(54%)</td>
<td>81(41%)</td>
<td>685(41%)</td>
</tr>
<tr>
<td>3 &amp; 9</td>
<td>19(26%)</td>
<td>53(27%)</td>
<td>593(36%)</td>
</tr>
<tr>
<td>4 &amp; 8</td>
<td>4(6%)</td>
<td>35(18%)</td>
<td>207(15%)</td>
</tr>
<tr>
<td>Total</td>
<td>72(100%)</td>
<td>197(100%)</td>
<td>1671(100%)</td>
</tr>
</tbody>
</table>

The proportion of occupants with a 30 degree forward component increases to 54% amongst the fatally injured occupants. The 2 o’clock and 10 o’clock impacts were more frequently associated with fatal injury impacts, of the 685 that occurred 6% were fatal compared to 3% of the 3 and 9 o’clock impacts. The direction of force distribution was found to vary with the nature of the striking object. The fatal 2 and 10 o’clock impacts occurred mainly when the bullet object was a truck or a pole. 66% of fatal pole impacts and 66% of fatal truck impacts were at 2 or 10 o’clock compared with only 31% of fatal car to car side impacts. The impact directions of fatal car to car impacts were more widely distributed, 31% were also at 4 and 8 o’clock.

In the accident population oblique impacts with poles were more often fatal than perpendicular impacts. There were 94 (41%) pole impacts with a force direction of 2 or 10 o’clock and 83 (37%) with perpendicular impacts. 20 (21%) of the oblique impacts were fatal compared with only 8 (10%) of the 3 and 9 o’clock impacts. A similar pattern existed for those occupants slightly injured.

Both sets of test proposals appear to simulate well the force directions applied in fatal side impacts with cars. The majority of fatal impacts were not with cars however and the more common, more often oblique, fatal impacts with poles and trucks were less well represented. The variation of the principle direction of force with striking object is believed to relate to the different accident circumstances involved. Car to car side impacts are often intersection collisions whereas car to pole impacts may more frequently be due to a loss of control.
3 BARRIER CHARACTERISTICS

3.1 Nature of bullet objects

The EEVC mobile barrier is designed to simulate a typical car in stiffness with a width of 158 cm and a mass of 950 kg. The US barrier is much stiffer with a mass of 1364 kg and a width of 168 cm and is more typical of a light truck. The ground clearance of the EEVC barrier is 30 cm while the NHTSA barrier is 2 cm lower.

No field data have been collected where the effective stiffness of the bullet object has been measured but the stiffness can be crudely classified according to the type of the bullet object. In general cars can be considered to be amongst the softest group of objects with trucks, utility poles and trees amongst the most stiff. The distribution of the bullet objects found amongst the field data is shown in Table 3 for all struck side occupants, those seriously injured, and those killed.

Table 3 Striking object distribution for struck side occupants and all fatally injured occupants

<table>
<thead>
<tr>
<th>Striking Object</th>
<th>Severities</th>
<th>All</th>
<th>Fatally</th>
<th>Seriously</th>
<th>Fatally Injured</th>
<th>Injured</th>
<th>Injured Occ'pants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>1026(60%)</td>
<td>77(39%)</td>
<td>23(30%)</td>
<td>38(36%)</td>
<td>38(36%)</td>
<td>77(39%)</td>
<td>23(30%)</td>
</tr>
<tr>
<td>Truck/Bus</td>
<td>216(13%)</td>
<td>29(15%)</td>
<td>16(21%)</td>
<td>19(18%)</td>
<td>19(18%)</td>
<td>29(15%)</td>
<td>16(21%)</td>
</tr>
<tr>
<td>LGV</td>
<td>96(6%)</td>
<td>10(5%)</td>
<td>2(3%)</td>
<td>2(1%)</td>
<td>2(1%)</td>
<td>10(5%)</td>
<td>2(3%)</td>
</tr>
<tr>
<td>Pole/tree</td>
<td>227(13%)</td>
<td>62(31%)</td>
<td>32(43%)</td>
<td>43(41%)</td>
<td>43(41%)</td>
<td>62(31%)</td>
<td>32(43%)</td>
</tr>
<tr>
<td>Other vehicle</td>
<td>7(4%)</td>
<td>2(1%)</td>
<td></td>
<td></td>
<td></td>
<td>7(4%)</td>
<td>2(1%)</td>
</tr>
<tr>
<td>Other object</td>
<td>135(8%)</td>
<td>18(9%)</td>
<td>2(3%)</td>
<td>3(2%)</td>
<td></td>
<td>135(8%)</td>
<td>18(9%)</td>
</tr>
<tr>
<td>Total</td>
<td>1707(100%)</td>
<td>197(100%)</td>
<td>75(100%)</td>
<td>105(100%)</td>
<td>105(100%)</td>
<td>197(100%)</td>
<td>75(100%)</td>
</tr>
</tbody>
</table>

A car is by far the most common striking object, 1026 (60%) of all struck side occupants were in car to car collisions while poles and trucks were less common, representing about 13% of struck side occupants each. A different picture emerged amongst the seriously and fatally injured groups. 77 (39%) of the seriously injured and only 23 (30%) of the fatally injured struck side occupants were in cars struck by other cars. The most common object striking fatally injured occupants were trees or utility poles. Of the 227 struck side occupants in cars that struck poles or trees 32 (14%) died compared to only 23 (2%) of the 1026 that were struck...
by other cars. The death rate for occupants having impacts with trucks was 7%. Poles and trees are clearly particularly hazardous objects to collide with although impacts with cars are more common. This balance of injury risk and exposure results overall in similar numbers of fatalities due to each type of bullet object. Other studies have reported similar results. Hartemann described a three month population of side impact fatalities in France where 30% of casualties were struck by a car, 45% against a tree or pole and 17% struck by a truck. FARS data in the US described the involvement of cars, trucks and trees or poles as 31-33%, 27-36% and 31-42% respectively for fatal occupants in side collisions.

The effect of the height range of the fronts of the bullet cars was not determined within this analysis. It was therefore not possible to evaluate the relative consequences of the ground clearances of the two barriers.

The choice of a mobile barrier that has the characteristics of a car should result in new car designs that give optimum protection in car to car impacts. The level of protection in collisions with trucks and poles may be only slightly increased over current car designs. Therefore 60% of all side impact occupants and 30% of the fatal occupants would obtain maximum benefit from a car optimised for protection in car to car impacts. The group of struck side occupants in cars striking other objects and the unrestrained non-struck side occupants may well receive a lower level of protection. There were 1051 (32%) in the population of 3250 occupants in cars in side collisions. The 934 (29%) restrained non-struck side occupants are likely to receive only a minimal reduction in injuries.

The NHTSA test procedure would result in cars with protection optimised for impacts with objects with stiffness of light trucks. The test would be closely similar to the impact conditions of only 6% of struck side occupants in side collisions and 3% of the fatal occupants. However such a barrier would present a more severe impact to the test car than from a bullet vehicle of lower stiffness as the target cars structure would be required to be more rigid. The ability of the NHTSA barrier to deform both A-pillar and B-pillar resulting in side-down for struck side occupants appears to be an artificial benefit when car to car side impacts are examined.
If the barrier simulated a tree or pole only 13% of the whole population of struck side occupants would be represented as would 23% of those seriously injured. The proportion of fatal struck side occupants represented would rise to 43%.

Currently NHTSA is considering the retention of FMVSS 214 which incorporates a static test where a pole-like device is pushed into the side of the car. FMVSS 214 has been evaluated and has been shown to result in car designs that are effective in car to pole impacts. A test procedure that simulates car to car side impacts would seem to be less of a compromise when alongside an additional test examining the protection in pole impacts, particularly for the reduction of numbers of fatally injured occupants. The design of cars to protect occupants in side impacts with both cars and poles appears to be difficult although concept designs with external door beams have been discussed. There are no equivalent proposals for such a requirement in Europe however the future addition of a supplementary pole-like test procedure to the mobile barrier tests proposed does appear to have the potential for a further reduction in fatalities. In addition there were still 11,100 single vehicle fatalities that occurred in the US in 1987 and 2304 (21%) died in side impacts. FMVSS 214 is therefore not completely effective. A significant constraint may be the numbers of fatal head injuries caused by striking the pole. Thomas has shown that 59% of fatally injured struck side occupants who had their most severe injury to the head sustained these injuries as a result of striking an object outside the vehicle.

3.2 Impact speed

The EEVC proposed test procedure involves a barrier impact speed of 50 kph and the US proposes a 54 kph impact speed. The field data employs the CRASH3 computer program to estimate delta-v in a manner equivalent to its use within the US National Crash Severity Study. Table 4 shows the median values of delta-v for the cars of struck side occupants of each severity level in impacts with cars. CRASH3 does not estimate delta-v accurately for pole or truck impacts so the field data contains a high proportion of unknown values for these striking objects. Table 4 therefore only shows the values for car to car impacts. It was possible to estimate the delta-v of 491 vehicles, the remainder violated the assumptions of CRASH3. The use of CRASH3 provides an estimate of the impact severity to
the target car as measured by delta-\(v\). The
computer algorithm incorporates a number of
approximations in its implementation and its
accuracy has been questioned particularly by
those involved in accident reconstruction for
litigation purposes. Smith\(^1\) compares the
true and predicted delta-\(v\) values of 30 staged
side collisions using CRASH3 and shows that it
tends to produce an underestimate. CRASH3
does not appear to be suitable for individual
delta-\(v\) estimates and Smith states that it is
best used in statistical studies where the
under- and overestimates balance as much as
possible. There is also no widely accepted
alternative algorithm that is more capable of
estimating the impact severity to a wide range
of car models.
Table 4 Median delta-v of struck side occupants when struck by cars

<table>
<thead>
<tr>
<th>Injury severity</th>
<th>Median Delta-v Car - Car Impacts of 25 kph</th>
<th>25th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>All injuries</td>
<td>24 kph</td>
<td>55%</td>
</tr>
<tr>
<td>Seriously injured</td>
<td>31 kph</td>
<td>24%</td>
</tr>
<tr>
<td>Fatally injured</td>
<td>43 kph</td>
<td>below lowest</td>
</tr>
</tbody>
</table>

The effect of the delta-v experienced in each of the test procedures will vary according to the mass ratio of the test. A car of the same mass as the barrier will have a delta-v of half the impact speed due to momentum conservation. If the barrier is heavier the delta-v will be correspondingly greater. The assumption that the barrier mass represents the mass of a typical car infers that the median delta-v expected in the tests is 25 kph. The percentile point that a 25 kph delta-v represents is therefore shown in Table 8. The median delta-v experienced by occupants of all injury severities is 24 kph so the severity of the EEVC test would represent these impacts well. The median delta-v of the seriously injured occupants in collisions with cars is 31 kph, above the nominal test delta-v as was that for the fatally injured casualties at 43 kph.

Rouhana\textsuperscript{14} reports that the National Crash Severity Study (NCSS) data shows a median delta-v of 27 kph for serious injuries and 50 kph for fatal occupants. Cesari\textsuperscript{15} found similar results in a small study of 39 car to car side impact collisions. He reported the mean delta-v for AIS 3 to 5 injuries to be 30 kph. Mackay\textsuperscript{14} summarising other studies also describes the typical delta-v resulting in AIS 3+ injuries to be in the region of 30 kph with the 75th percentile delta-v for these injuries at 38 kph.

The typical delta-v of 25 kph expected of the range of test impacts is therefore only close to the median value of car to car impacts of all injury severities. It is 6 kph too low for serious injury collisions and 18 kph too low to represent fatal collisions. The NHTSA barrier is heavier and will result in a median delta-v of 35 kph with the European car fleet. This value is between the median values for serious and fatal collisions and would appear to be a much closer compromise value than that obtained through use of the EEVC barrier.
It is of note that NHTSA in its Preliminary Regulatory Impact Analysis1' states that NCSS data gives the median impact speed of serious injury accidents as 56 kph with an additional forward component of 28 kph. The US test speed therefore represents the lower threshold of serious injury and is inherently less severe than most serious and most fatal side collisions in the US.

When a test proposal is developed the injuries that are to be reduced first have to be defined. The impact severity of the test car can then be at the level by which 50% of these injuries have occurred. The effectiveness of the test is optimised when the acceptable dummy measurements represent the level where 50% of the population sustain the defined injuries. If the crash severity to the vehicle is below the level where 50% of injuries are sustained the acceptable dummy measurements have to be correspondingly reduced if the test is to be optimised for the population. The impact severity of the test cars resulting from the EEVC procedure are typically below the severity level where 50% of the population of struck side occupants sustain serious injuries. An equivalent situation exists comparing the NHTSA test to the US accident data. The permitted levels of dummy measurement in the EEVC test however are at the 50th percentile level although NHTSA is considering a range of levels.

The impact severity measures to the vehicle and to the occupant are not the same. The severity to the vehicle is usually measured by an estimate of delta-v; the velocity change of the target car during the time when the deformation is occurring. Experimental collisions however suggest that the impact severity to the struck side occupants relates best to the travelling speed of the bullet car at the moment of impact. The link between the measures of impact severity to the vehicle and the occupant from field and experimental data is unclear.

Experimental collisions suggest that the test impact speed is at the level seen to result in severe injuries in cadaver tests while the field data from the UK, the US and France indicates it is not. Therefore there is a discrepancy between the impact severity to the car measured using CRASH3 on field data and the impact severity to the occupant measured in experimental data. It is recommended that a study be performed to examine this relationship between the two measures to clarify the situation.
The development of test procedures has taken a pragmatic approach addressing the types of impact that are the most easily reduced in severity while being commonly associated with serious or fatal injuries. They necessarily represent a compromise of many parameters observed to influence injury outcome in field data. Hobbs' suggests that any test procedure should adequately represent the side impact injury process. This infers that the test should have the impact severity of a typical fatal collision and that the loads to the dummies should be transmitted in a reasonably realistic fashion if the numbers of fatalities are to be reduced.

There appear to be some significant differences between the test conditions and those in which many people die. Both test proposals simulate a car to car side impact but the field data suggest that only 36% of the fatally injured struck side occupants are in cars struck by other cars. More fatalities result from collisions with more hostile objects such as trees, trucks or lamp-posts. The proposed test conditions will have some effect on this group of casualties but levels of protection will be optimised for a car to car side impact. The tests will however be a better simulation of non-fatal side impacts as collisions with cars form 39% of serious injury collisions and 60% of all side impacts. The NHSTA considerations for pole impact protection could provide an important degree of additional protection for car occupants. The introduction of an equivalent measure in Europe could help to address an important group of fatalities. However fatal head injuries from a contact directly on the pole are probably not preventable currently and are likely to be a limiting factor to the effectiveness of any regulation.

Both barriers have the front face parallel to the side of the test vehicle at impact although the NHTSA barrier has a crabbled motion simulating the forward velocity of the test car. The forces are applied with a clock direction of 9 and 10 o’clock for the EEVC and the NHTSA barrier respectively. The most common direction of force in the field data has a forward component and is at either 2 o’clock or 10 o’clock. This is particularly evident amongst fatal side impacts where 54% have one of these two directions of force. This trend mainly occurs in side impacts with poles and trucks. Fatal side impacts with cars have a fairly uniform spread of directions between 2 and 4 o’clock and 8 and
10 o'clock. Neither barrier is clearly more realistic than the other. A test to simulate pole impacts, however, would be more typical of real world serious and fatal pole impacts if it reflected the more frequent oblique impacts.

The impact speeds of the EEVC and NHTSA barriers are 50 kph and 54 kph respectively. If the test car mass is the same as the barrier the delta-v will be 25 kph, if the car mass is greater the delta-v will be lower. The field data has shown that the barrier mass is below the typical mass of bullet cars in the field and the range of delta-v when the current car population is tested is therefore below the range experienced in the field. A test delta-v of 25 kph is close to the median value for side impacts of all severities; 55% of car to car collisions are less severe. It is not close to the median of 31 kph for serious injury side collisions and is below the lowest value for fatal car to car impacts. Neither test reproduces the impact severity to the vehicle in impacts where the more serious or fatal injuries occur. If the test requirements are expected to address fatal car to car side impacts the delta-v should be 43 kph and if it is to address those where serious injuries are sustained the test delta-v should be 31 kph. The experience in France and the US appears to be similar.

Experimental collisions with cadavers and dummies suggest that the tests do reflect the impact severity to the occupant and that there is therefore a discrepancy between field data and experimental data. This difference needs to be resolved before the tests can be clearly seen to be sufficiently severe.

The benefits from the new designs of cars that pass either of the proposed regulations will apply mainly to struck side occupants. These occupants represent the majority of serious and fatally injured car occupants in side collisions. The reduction in the injuries of restrained non-struck side occupants will be less as they only contact the intruding side structures of cars in impacts with high intrusion. These casualties necessarily take a lower priority than struck side occupants but they still represent almost 30% of fatal and seriously injured casualties. There is a need for improved protection for these occupants, possibly using restraint systems that are more effective in perpendicular impacts.
This comparison of field accident data and the parameters of the two dynamic tests has demonstrated a number of factors which may limit the effectiveness of the future legislation. However it is the opinion of the authors that either test has the potential of reducing the numbers of side impact fatalities and that either test would serve as a useful initial stage towards the objective of preventing side impact injuries. The effect of the future legislation has to be monitored as it is considered that it will need to be fine tuned progressively as accident experience is built up.

5 CONCLUSIONS

- Most fatal impacts are a result of collisions with objects other than cars. Fatal tree and utility poles collisions are as common as car collisions. A car-like barrier reproduces serious injury collisions better than it does fatal side impacts.

- The BBVC test procedure typically results in a target car delta-v that is lower than that of most serious and nearly all fatal collisions calculated using CRASH3.

- Both tests apply the forces to the test car along a realistic direction to represent car to car side impacts. Fatal pole and truck accidents are more often oblique.

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