

# Injury Reduction Opportunities of Far side Impact Countermeasures

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**ABSTRACT** – Over 17,000 non-struck or far side occupants in side and rollover crashes are seriously or fatally injured annually in the US. Although no legal or rating tests exist for far side crashes, test methods including appropriate dummies as well as countermeasures have been recently suggested. The aim of this study was to establish the incidence and risk of injury / fatality as a function of vehicle change in velocity ( $\Delta v$ ) for the most frequent injuries of belted, far side occupants in side impacts. The study was based upon the NASS/CDS 1995-2006 records of 5,653 occupants exposed to a far side crash. 401 of these were seriously or fatally injured. Combining this data with new and previously published crash test results, the potential opportunities of various concepts of far side countermeasures were evaluated. Head/thorax injuries caused by interaction with the struck side interior were found to dominate. Countermeasures such as side support airbags and altered three-point belt geometry (e.g. four-point belts) are relevant for  $\Delta v$  of at least 20-30 km/h. The opportunity for mitigating AIS3+ injuries in these severity ranges was found to be 19%- 57%. Countermeasures such as struck-side curtains are able to provide cushioning at  $\Delta v$  30 to 50 km/h, which would cover almost a third of all fatalities.

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## INTRODUCTION

To date, there are no rating systems or legal regulations that evaluate or ensure protection of non-struck side occupants involved in a side crash. Likewise, current passenger vehicles lack protection measures for far side struck occupants, such as the head and thorax protecting side airbags which have been designed to protect struck side occupants in the car. A recent analysis of side crashes based on the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) 1993-2002, a period in which most cars were not equipped with head and thorax protecting side airbags, showed the ratio of harm between near and non-struck or far side occupants was a factor of approximately three (Gabler et al, 2005). Therefore, nearside occupant protection has justifiably held priority over far side occupant protection. However, as the overall level of protection for nearside occupants increases this harm ratio is likely to change. In addition, nearside occupants may benefit from far side countermeasures if occupant-to-occupant injuries can be avoided.

To address these concerns, a global far side occupant research consortium was developed and commissioned in 2004 to meet the need for improved far side impact occupant protection (Fildes et al, 2005). Within the scope of this consortium, crash-test methods including

dummies are in the final phase of development and proposal. When evaluating the ability of a far side countermeasure to restrain an occupant from colliding with the struck side or another occupant, a full-scale test is preferable. A cost-effective alternative, however, is to conduct a sled test with a transversely mounted seat (Bostrom et al 2003). Fildes et al (2002) found that the nearside dummies EuroSID and BioSID were unsuitable for far side occupant countermeasure evaluation. Fildes et al (2006) later reported that a lumbar modification of the BioSID improved the applicability of this dummy for far side simulation considerably. Pintar et al (2007) found that the WorldSID and the Thor are suitable for far side impact dummy tests.

Three-point belt-restrained, far side struck occupants are primarily restrained only by the lap belt. Sled tests and full scale crash tests (Digges and Dalmotas, 2001; Fildes et al, 2002; Bostrom et al 2003) have shown that, in a side impact, the far side occupant slides out of the seat belt and flails toward the struck side of the vehicle. In real world crashes, the occupant then collides with the surfaces or objects on the nearside including the intruded nearside door, the adjacent seat, and the nearside occupant.

Several far side impact injury countermeasures have been proposed and evaluated. The countermeasures include belt pretensioning

(Stolinski et al, 1999; Douglas et al, 2007), the Side Support Airbag (SSA) (Bostrom and Haland, 2005), reversed geometry shoulder belts (Bostrom et al, 2005), criss-cross shoulder belts (Bostrom and Haland, 2005), the V-shaped 4-point belt (Rouhana et al, 2003 and 2006) and even an adjacent occupant (Frampton et al, 1998).

Digges and Gabler (2006) used NASS/CDS 1995-2004 to estimate the population of front seat occupants exposed to far side crashes and those with MAIS 3+ and fatal injuries. Digges observed that countermeasures applicable to far side planar crashes might also provide opportunities for risk reduction in some far side rollovers. As shown in Table 1, an estimated 5,706 MAIS3+F occupants were exposed to either far side planar impacts or rollovers. Some proposed far side impact countermeasures, e.g. side curtains, may also be effective for unbelted occupants exposed to either far side planar impacts or rollovers. Including unbelted occupants in the calculation increases the target population to over 17,000 MAIS3+F occupants exposed to either far side planar impacts or rollovers.

**Table 1. Annual MAIS 3+F Injuries from NASS/CDS in Nearside and Far side Crashes by Crash Type, Direction and Belt Use (from Digges and Gabler, 2006).**

Crash Type / Belt Use	Planar	Roll	Total
Far Belted	2,166	3,540	5,706
Far Unbelted	5,095	6,325	11,420
Far Total	7,261	9,865	17,126

Advanced belt systems such as criss-cross belts, V-shaped 4-point (V-4) belts or rucksack belts, shown in Figure 1, would benefit not only far side struck occupants, but occupants subjected to frontal impacts as well. It is important though to design these belts not to cause new injury patterns such as neck injuries. Research is underway to gauge the potential for any restraint to cause neck injuries (Fildes et al 2005).



**Figure 1. Three versions of altered 3-point belt geometry, criss cross, V4 and rucksack.**

In a frontal impact, the more symmetrical, thoracic loading provided by these belt systems may help to reduce thoracic injuries (Bostrom and Haland, 2005; Rouhana et al, 2003). Seat belt systems, which improve restraint of the far side occupant, may also benefit the nearside occupant. In a side crash where there are two adjacent front seat occupants, the nearside occupant may be struck on one side by the deformed side structure and on the opposite side by the adjacent, far side, occupant.

It is critical to understand that median injury test conditions may represent only a minimal injury risk. Consequently, tests conducted under these conditions may result in low injury assessment outcomes. Injury incidence is a result of both exposure and risk. For this reason it is crucial to determine exposure and risk as a function of crash severity to compute the opportunities of countermeasures.

The aim of this study was to evaluate the potential opportunities of far side countermeasures to reduce injuries for belted far side occupants in planar side impact crashes. The aim was fulfilled, using NASS/CDS data to prioritize which body regions to protect, by identifying which injury sources to avoid, and then determining the cumulative  $\Delta v$  (vehicle change of velocity) - distribution of these injuries. In addition, risk as a function of  $\Delta v$  was derived for the prioritized injuries as well as for fatalities. The next step was to evaluate the ability of various far side countermeasure concepts to mitigate the prioritized source of injuries over specified ranges of  $\Delta v$ . This evaluation was based on far side crash tests, some performed for this study and some previously published. Finally, an opportunity evaluation of these countermeasures, in terms of actual numbers and percentile reduction of the prioritized injuries and fatalities, was performed.

## METHODS

The method section is divided into two sub-sections. In the first sub-section, *Prioritized injuries*, the method of prioritizing which body region to protect and source of injury to avoid and finding the cumulative  $\Delta v$ -distribution of these injuries is outlined. In the second sub-section, *Countermeasure opportunity*, the method of estimating the opportunity of far side countermeasures in terms of reduction of the prioritized injuries is described.

**Table 2. Belted U.S. passenger vehicle occupants exposed to far side impact (NASS / CDS 1995-2006).**

	Number of Cases (Unweighted)	Number of Cases (Weighted)	Annual Cases (Weighted)
<b>Exposed Occupants</b>	5,653	3,110,986	259,249
<b>MAIS3+ Occupants</b>	372	24,880	2,073
<b>MAIS3+F Occupants</b>	401	27,186	2,265
<b>Fatalities</b>	107	5,468	456

**Prioritized injuries**

Several earlier studies (Digges and Dalmotas, 2001; Gabler et al, 2005) have identified the head and chest as priorities for the development of far side crash countermeasures. For this opportunity study, this issue was revisited using the National Automotive Sampling System / Crash Data Analysis database (NASS/CDS)

1995-2006. This sub-section outlines the method of prioritizing far side occupant injuries.

Cases for the analysis were restricted to car or light truck occupants exposed to far side impact. The analysis was restricted to either drivers or right front passengers 12 years or older. Only occupants restrained by a three-point safety belt were included. Rollover crashes were excluded.

**Table 3. List, feature, examples, test specifications and references of the analyzed concepts of far side countermeasures.**

Countermeasure	Feature	Examples	$\Delta v$ , angle, dummy	Reference
<b>Belt pretensioner</b>	Reduce slack and tighten the belt by various degrees	Pyrotechnical and electrical retractor, buckle and latch plate pretensioners	30 km/h, 30-90 deg, Numerical model of human	Douglas et al 2007
<b>Inboard side support</b>	Restrain the occupant from moving inboard	Side support airbags, side support wings	24 km/h, 60&90 deg, BioSID spring spine	Bostrom and Haland, 2005
<b>Altered 3-point belt geometry</b>	Restrain the occupant from moving inboard	Criss-cross, reversible 3-point, rucksack-belt, V-shaped 4-point belt (V4)	24 km/h, 60&90 deg, BioSID spring spine	Bostrom and Haland, 2005
			About 24 km/h (FMVSS214) Post-Mortem Human Subjects	Rouhana et al 2006
			30 km/h, 90 deg, Thor	Performed for this study
<b>Nearside head and thorax airbags</b>	Provide cushioning between deformed struck side and occupant	Head and thorax airbags, inflatable curtain, window bags	50 km/h, 90 deg, WorldSID	Performed for this study

As shown in Table 2, the result was over 5,600 belted, adult, case occupants exposed to far side impact from 1995-2006. 372 case occupants suffered at least one serious injury (AIS level 3 or higher). Over 100 case occupants were fatally injured. The MAIS3+F category tabulates those occupants either seriously or fatally injured. This category includes occupants who did not receive an AIS3+ injury, but who died.

NASS/CDS weights were applied to these cases to produce national estimates of far side impact exposure and injury outcomes. On an annual basis in the U.S., over 250,000 belted, front seat occupants are exposed to far side impact. Over 2,200 of these occupants are seriously injured. An estimated 456 occupants are fatally injured each year in far side impacts in the U.S.

Based on this data, the body regions requiring protection, and their associated sources of injury, were prioritized. That is, the most frequent AIS3+ injured body regions and their most frequent injury sources were selected. In addition, the distribution of exposure versus  $\Delta v$  and the distribution of risk versus  $\Delta v$  were derived.

### Countermeasure opportunity

The previous section has described how far side impact injuries and injury sources were prioritized for countermeasure development. To mitigate these injuries, a number of countermeasure concepts, described in Table 3, were evaluated in sled tests and numerical

simulations. The simulations, some run for this study and some previously published, are listed in Table 3. The validity of using a sled test to replicate a full-scale test was described by Bostrom et al 2003. The applicability of using a BioSID spring spine, Thor or WorldSID was shown by Fildes et al (2006) and Pintar et al (2007). In the Bostrom and Haland (2005) sled tests the deformed struck side was simulated with a padded steel pillar. In the WorldSID 50 km/h sled test (performed for this study) the intruded side and center console were taken from a full scale IIHS test of a large passenger car where the impact speed were increased to 65 km/h ( $\Delta v$  30 km/h). The intruded side was reinforced and moved closer to the occupant to a distance (0,6 m head-to-door) corresponding to what would be expected in a real-life crash with similar  $\Delta v$  (NASS/CDS-data).

The ability of each countermeasure to protect occupants was simplified to an estimation of those  $\Delta v$  ranges for which the countermeasures are likely to be effective in mitigating the prioritized injuries. In these  $\Delta v$  ranges, a 100% effectiveness level was assumed. While production countermeasures are unlikely to achieve 100% effectiveness, this approach allows us to compute the upper limit for safety opportunities. Countermeasures with lower effectiveness would, of course, have lower safety benefits. For example a 50% effectiveness level would result in half the number of saved occupants.

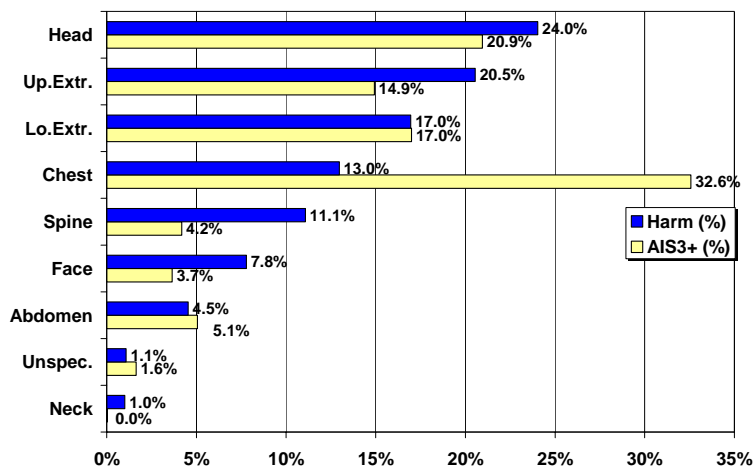


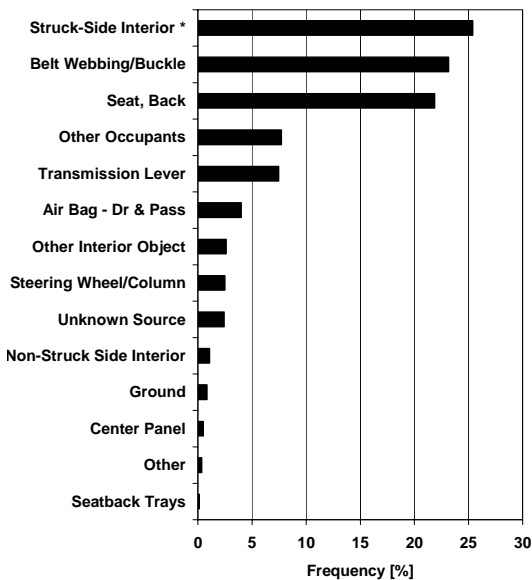
Figure 2. Distribution of injuries by body region (NASS/CDS 1995-2006).

## RESULTS

### Prioritized injuries

Figure 2 shows the resulting distribution by injured body region of serious injuries and harm to far side struck occupants. Harm is a measure of the social cost of all injuries suffered by an occupant including both medical and indirect costs, such as loss of wages (Gabler et al, 2005).

The priorities for far side impact injury countermeasures are protection of the head and chest of the far side struck occupant. The chest was the body region that most frequently incurred serious injury in far side impact (33%). The head accounted for the second highest percentage of serious injuries (21%). Together the head and chest accounted for over half of all serious injuries in far side impacts. Figure 2 also shows the surprisingly large number of serious injuries to the extremities. Together, the upper and lower extremities accounted for a third of all serious injuries.

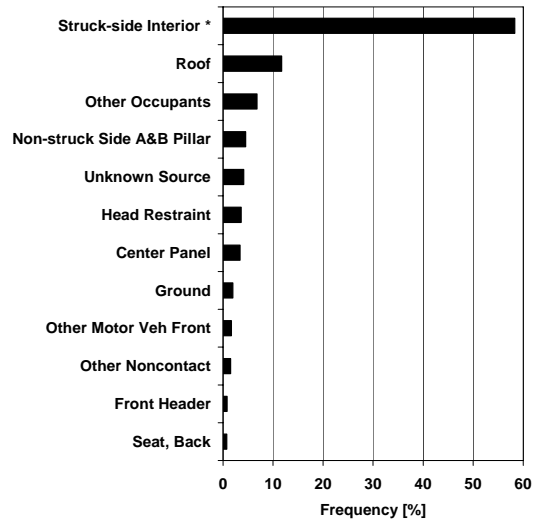


\* Includes window frame, hardware and B-pillar

**Figure 3. Distribution of AIS3+ chest injuries by injury source (NASS/CDS 1995- 2006).**

As shown in Figure 3, the majority of AIS3+ chest injuries were the result of occupant interaction with the struck side interior, the seat belt, seat back, and other occupants. Together these four contact sources accounted for over 70% of all serious chest injuries.

Figure 4 shows that more than half of all serious head injuries resulted from impact with the struck side interior. Head impacts with the roof and other occupants accounted for an additional 18% of serious injuries.



\* Includes window frame, hardware, panel, B-pillar, side rail, and B-pillar attachment

**Figure 4. Distribution of AIS3+ head injuries by injury source (NASS/CDS 1995-2006).**

These analyses suggest that the two priorities for occupant protection are the prevention of occupant collision with the struck side interior or the struck side occupant seat. Additional priorities are the prevention of collision with an adjacent occupant, and improvements of restraints to reduce belt-related thoracic injuries, e.g. through load-limiting belts.

Each year in the U.S., approximately 1,200 far side struck occupants incur an AIS3+ head or chest injury. Approximately 450 far side struck occupants are fatally injured. Figure 5 and 6 presents the incidence and risk of receiving an injury to the head-chest region as a function of lateral  $\Delta v$ . These figures also present the incidence and risk of fatality in a far side crash.

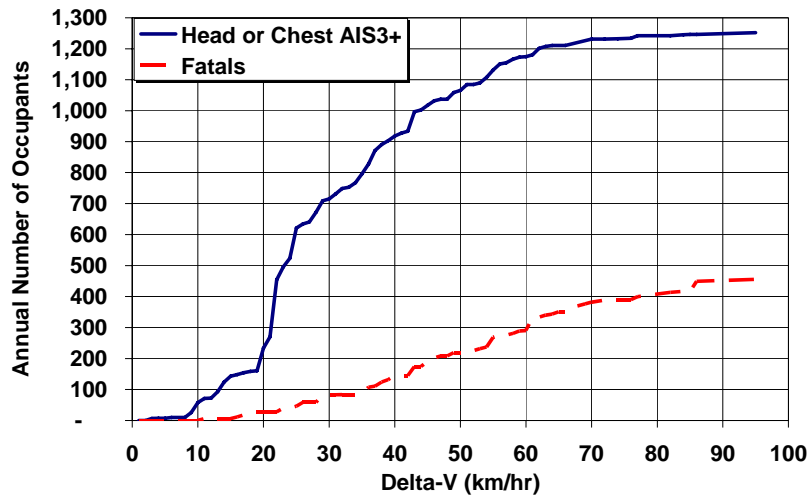


Figure 5. Annual number of fatality and head/chest injury in far side crashes by lateral  $\Delta v$  (NASS 1995-2005, Age 12+, front seat only).

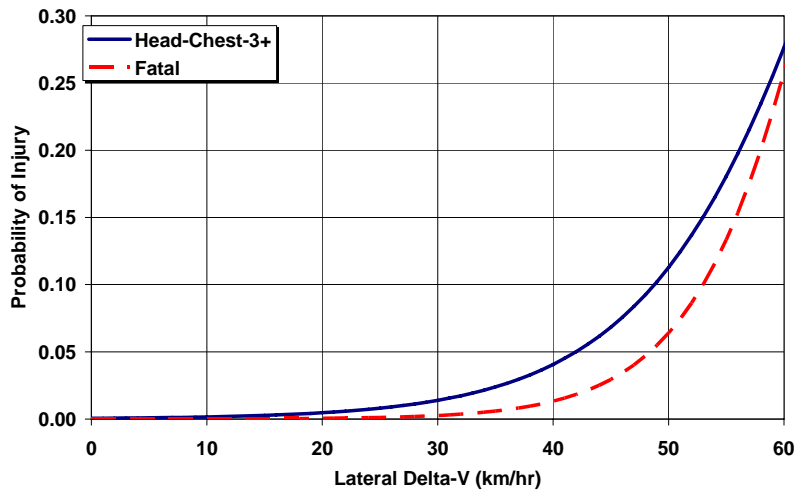


Figure 6. Probability of fatality and head/chest injury in far side crashes by lateral  $\Delta v$  (NASS 1995-2005, Age 12+, front seat only).

Table 4. Estimated relevant occupants and opportunity percentage of far side countermeasures mitigating AIS3+ head or chest injuries within the  $\Delta v$  range.

$\Delta v$ effectiveness range	Total occupants with AIS3+ head or chest injuries – baseline	Relevant occupants within $\Delta v$ Range	Overall opportunity percentage below threshold
0-20 km/hr	1,252	233	19%
0-30 km/hr	1,252	715	57%
0-40 km/hr	1,252	918	73%

Table 5. Estimated relevant occupants and opportunity percentage of far side countermeasures reducing fatalities within the  $\Delta v$  range.

$\Delta v$ effectiveness range	Total fatalities (baseline)	Relevant occupants within $\Delta v$ Range	Overall opportunity percentage below threshold
0-20 km/hr	456	27	6%
0-30 km/hr	456	83	18%
0-40 km/hr	456	145	32%
0-50 km/hr	456	218	48%
30-50 km/hr	456	136	30%

## Countermeasure opportunity

As a reference, as shown in Figure 7, a standard 3-point belted BioSID spring spine dummy slips out of the shoulder part of the belt with a resulting impact on the simulated intruded struck side. The analyzed simulations of the countermeasures listed in Table 3 showed considerable reduced head and chest excursions.

According to Douglas et al model (2007), belt pretensioning keeps the belt from slipping off the shoulder in 30 km/h far-side crashes. The location of the shoulder belt anchorage was found to influence head excursion for pretensioned belts. However, additional simulations are needed to determine the speed range over which pretensioned belts will prevent the head from contacting the intruding structure. This research is continuing and will be reported later. Opportunities for this technology will be reported as well.

As illustrative examples, Figure 8 and 9 shows the protective performance of a side support airbag and altered 3-point belt geometry in 90 degree BioSID spring spine/Thor sled tests in 24 and 30 km/h. The evaluated side support airbag in Figure 8 was smaller compared with a standard thorax (outboard) side airbag. Also, the bag was not ventilated. The evaluated altered belt in Figure 9 was an added 2-point rucksack belt (together with a standard 3-point belt). These interventions were found to restrain the occupant sufficiently to avoid interaction with the struck side over the evaluated  $\Delta v$  range. The ability of these countermeasures to prevent thoracic injuries from the belt webbing/buckle, seat back and other occupants (the bulk of the remaining thorax injuries) was not obvious from the Figures. However, the dummy thorax readings indicated no such injuries.

As an illustrative example, Figure 10 shows the protective performance of a side curtain with long stand up time in WorldSID sled tests. The 90 degree tests at 50 km/h  $\Delta v$ , were carried out to replicate the interaction between a far side occupant and a struck side triggered curtain in conditions resembling real-life crashes for this type of severity. These tests showed the occupant to be cushioned by the curtain with a resulting HIC15 of 741 (85g), neck tension/compression of 778N/2376N. Note that the head-to-curtain impact speed was in the order of what would

have been expected in a near side legal or rating test (typically lateral  $\Delta v$  of 20-30 km/h).

The relevance of a countermeasure is defined as the range of crash attributes over which a countermeasure has the ability to mitigate injuries. For example, if an air bag deploys at  $\Delta v$  15 km/h and offers protection up to  $\Delta v$  50km/h, its  $\Delta v$  relevance would be 15 to 50 km/h. The injury reduction opportunity would be determined by the size of the relevant population injured during exposure to crashes between 15 and 50 km/h. The effectiveness is defined as the percentage of the injuries at all crash severities that could actually be mitigated by the countermeasure. The opportunity analysis provides insight into the magnitude of the injuries that might be addressed by a countermeasure. It does not attempt to estimate the effectiveness of the countermeasure.

Based on the incidence of injuries as a function of  $\Delta v$ , the relevance for protection against AIS3+ head or thorax injuries for  $\Delta v$ s of 20, 30 and 40 km/h were derived. The AIS3+ results expressed both in annual numbers and ratios of the total incidence are shown in Table 4. Out of the weighted 2073 MAIS3+ occupants (Table 2), 1252 had a head or thorax AIS3+ injury. According to Table 4, 233 out of the 1,252 occupants with AIS3+ injuries, that is 19%, were injured below 20 km/h of  $\Delta v$ . With a countermeasure relevant for  $\Delta v$  below 20 km/h, 233 or 19% of all occupants with AIS3+ injuries would have the opportunity for being mitigated.

The opportunities of countermeasures that are relevant in preventing fatal injuries in the  $\Delta v$  range of 0-50 km/h were derived. Note these fatalities may result from injuries to the head and chest, as well as other body regions. These results, expressed both in annual numbers and ratios of the total incidence, are shown in Table5.

According to crash tests shown in this paper and a recently published benefit analysis (Kahane, 2007), an inflatable side curtain, with suitable coverage area and stand-up time, could be an effective countermeasure for reducing far side fatality risk. For lower  $\Delta v$ s, the far side occupant would be unlikely to flail far enough to hit the struck side. For this study, we assume that a side curtain would be relevant in reducing a fatal risk in far side impacts in  $\Delta v$ s between 30 and 50 km/h.

As shown in Table 2, there are an estimated 456 fatalities of belted far side struck occupants in the U.S annually. As presented in Table 5, 18% of the fatalities occurred for a lateral  $\Delta v$  below 30 km/hr, and 48% of fatalities occurred for a lateral  $\Delta v$  below 50 km/h. Assuming relevance of the struck side curtain between 30 and 50

km/h, the countermeasure would prevent 136 US fatalities ( $456 \cdot (.48 \cdot .18)$ ) annually with an overall benefit of 30% ( $136 / 456$ ). This is consistent with the estimate made by Kahane (2007) that side curtains would reduce far side occupant fatality risk by 30%.



**Figure 7.** Photographs taken at 1, 75 and 150 ms from the Bostrom et al 2005 reference test with a BioSID spring spine at 90 degrees and  $\Delta v$  24 km/h. The HIC indicated a severe head injury.



**Figure 8.** Photographs taken at 1, 75 and 150 ms from the Bostrom et al 2005 side support airbag test with a BioSID spring spine at 90 degrees and  $\Delta v$  24 km/h.



**Figure 9.** Photographs (flipped) at 1, 75 and 150 ms from tests conducted for this study with a Thor restrained by an extra belt (no load limiting) at 90 degrees and  $\Delta v$  30 km/h.



**Figure 10. Photographs (flipped) at 1, 50 and 100 ms from tests conducted for this study with a belted WorldSID interacting with an inflatable curtain at 90 degrees and  $\Delta v$  50 km/h.**

**Table 6. Estimated opportunity of far side countermeasures mitigating AIS3+ and fatalities at the  $\Delta v$  threshold.**

Conceptual countermeasure	$\Delta v$ threshold (km/h)	Far side AIS3+	Far side fatalities
Altered seat belt (4-point)	0-30	715 (57%)	83 (18%)
Side support airbags	0-30	715 (57%)	83 (18%)
Side curtain	30-50	350 (28%)	136 (30%)

## DISCUSSION

Head or thorax injuries caused by contact with the struck side are the dominant type of injury among belted far side occupants in planar side impacts. In contrast to the situation in belted nearside and frontal impacts, the injury mechanism seems to be bimodal in that the occupant may or may not reach the opposite side of the car. Although over half of all serious injuries take place for  $\Delta v$  below 30 km/h (Gabler et al, 2005), the risk of a serious head/thorax injury is small (3%). A full-scale replication of a  $\Delta v$  30 km/h far side impact crash is likely to reveal dummy readings indicating only a small risk of serious or fatal injury.

Nevertheless, the countermeasures evaluated in this study, do, to various degrees, either restrain a belted far side occupant from colliding with the

struck side or cushion the struck side in planar side impacts, therefore, the potential opportunity is considerable. The opportunities of three promising conceptual countermeasures are summarized in Table 6.

Other injuries, such as injuries caused by the countermeasure or extremity injuries (majority of the remaining), were not addressed in this study. Also not addressed was the opportunity of the evaluated countermeasures to protect nearside occupants (7% of all far side occupant head injuries were caused by occupant-to-occupant interaction) or to protect occupants exposed to other crash circumstances such as rollover, oblique or high-speed frontal crashes.

This opportunity study will be followed by a benefit study where the associated reduction of harm will be evaluated.

## CONCLUSIONS

Far side occupant AIS3+ and fatal incidence and risk curves are presented here for the first time. Based on this data a far side countermeasure opportunity analysis was performed revealing a potential opportunity in the same order (in terms of percent injury/fatality reduction) as common nearside and frontal impact countermeasures. The key findings of this study were:

- Head and chest occupant interaction with the struck side interior are the most important interactions to mitigate.
- A countermeasure 100% effective in reducing the risk of a serious or fatal head and thorax injury up to a  $\Delta v$  of 20 and 30 km/h would potentially reduce the number of serious injuries by 19 and 57% respectively. According to crash tests shown or referred to in this study side support airbags and altered 3-point belt geometry could constitute such countermeasures. Possible injuries being induced by these countermeasures were disregarded.
- A countermeasure 100% effective in reducing the risk of fatality in far side impacts for  $\Delta v$  between 30 and 50 km/h would reduce the number of fatalities by 30%. According to crash tests shown in this paper and a recently published benefit analysis, an inflatable curtain, with suitable coverage area and stand-up time, could constitute such a countermeasure.

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