Benefit analysis for the introduction of a Full Width Frontal Impact Test

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BENEFIT ANALYSIS FOR THE INTRODUCTION OF A FULL WIDTH FRONTAL IMPACT TEST

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Executive summary
The APROSYS integrated project on Advanced Protection Systems is an EC 6th Framework project focusing on scientific and technological development in the field of vehicle passive safety. APROSYS aims to offer a significant contribution to reducing the number of road accident victims in Europe through development of critical technologies that improve passive safety for all European road users in all relevant accident types and severities.

APROSYS sub-project 1 (SP1) is titled ‘Car Accidents’, and within this is work package 1.2 (WP1.2) titled ‘Advanced Frontal Impact’. The aim of the frontal impact work package is to develop and evaluate a full width high deceleration frontal impact crash test suitable for regulatory application in Europe. This is known as the Advanced European Full Width (AE-FW) test. As part of this, WP1.2 aims to perform associated accident and cost benefit analysis for the introduction of this AE-FW test.

A benefit analysis was performed for WP1.2 by Stanzel [1] as part of APROSYS SP8.3. Stanzel used the German GIDAS (German In-Depth Accident Study) database to undertake the benefit analysis. The approach and methodology applied in Stanzel’s analysis appeared to be good and were based on the ‘equal risk at test speed’ assumption. The analysis predicted that the benefit for the introduction of a full width frontal impact test would be ‘marginal’, estimating a reduction in MAIS 2+ injuries of approximately 1.9 percent. However, an initial review of the benefit analysis indicated that there were some key factors that required further investigation before the results of the analysis were accepted as conclusive.

This work had two main objectives. The first objective was to perform a critical review of the benefit analysis performed by Stanzel. This was required in order to examine some key factors that might have influenced the conclusions in the Stanzel benefit analysis, but which did not appear to have been investigated in that work. The second objective was to calculate a benefit for the introduction of a full width frontal impact test using Great Britain (GB) accident data, namely the CCIS (Co-operative Crash Injury Study) database and the STATS19 national accident statistics.

The review indicated that the results of Stanzel’s benefit analysis were unreliable due to the sensitivity of the risk curves used as well as the limiting effect of the assumptions that there would only be benefit in full width impacts and only up to the current level of performance in offset impacts.

A different methodology was used to calculate the benefit for Great Britain (GB). The benefit analysis showed that the introduction of a full width frontal impact test would be expected to reduce annual fatalities in GB by 2 to 3 percent (approximately 47 occupants) and serious casualties by 5 to 6 percent (approximately 813 occupants). This is a significant benefit that is greater than was estimated in the Stanzel benefit analysis. However, it should be noted that the predicted benefit for GB is a first estimate, and this has a considerable tolerance that depends on the precise performance limits that are eventually chosen for the full width frontal impact test.

Recommendations for further work to refine the benefit analysis are given.
1 Introduction

The APROSYS integrated project on Advanced Protection Systems is an EC 6th Framework project focusing on scientific and technological development in the field of vehicle passive safety. APROSYS aims to offer a significant contribution to reducing the number of road accident victims in Europe through development of critical technologies that improve passive safety for all European road users in all relevant accident types and severities.

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A benefit analysis was performed for WP1.2 by Stanzel [1] as part of APROSYS SP8.3. Stanzel used the German GIDAS (German In-Depth Accident Study) database to undertake the benefit analysis. The approach and methodology applied in Stanzel’s analysis appeared to be good and were based on the ‘equal risk at test speed’ assumption. The analysis predicted that the benefit for the introduction of a full width frontal impact test would be ‘marginal’, estimating a reduction in MAIS 2+ injuries of approximately 1.9 percent. However, an initial review of the benefit analysis indicated that there were some key factors that required further investigation before the results of the analysis were accepted as conclusive.

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2 Review of Stanzel Benefit Analysis

The benefit analysis undertaken by Stanzel aimed to assess the benefit of the introduction of a full width frontal impact test. The approach and methodology applied in Stanzel’s analysis appeared to be good and were based on the ‘equal risk at test speed’ assumption. However, an initial review of the benefit analysis indicated that there were some key factors that required further investigation before the results of the analysis were accepted as conclusive. This section provides a summary of the Stanzel benefit analysis, followed by an investigation of the key factors.

2.1 Summary of Stanzel benefit analysis

The approach taken was to calculate the benefit that the introduction of a full width test would give for a fleet of cars that were ‘state-of-the-art’, or ‘NCAPable’ (i.e. already designed for the EuroNCAP 40% offset test at 64km/h). In this case, ‘state-of-the-art’ or ‘NCAPable’ was defined as being built in 1997 or later. The Stanzel benefit analysis was based on the GIDAS (German In-Depth Accident Study) database.

The main assumption used in this analysis was that a ‘future’ car designed for both the EuroNCAP offset test as well as the new full width test would provide equal protection for its occupants in each of these impact configurations, at the corresponding test speed (i.e. 64km/h in the offset test and 56 km/h in the full width test). In addition, it was assumed that the introduction of the full width test would only have a benefit for vehicles involved in full width overlaps in real-world crashes.

The risk of sustaining MAIS 2+ injury levels in a ‘state-of-the-art’ car in full width and offset frontal crashes for increasing delta-V was calculated. In cases where delta-V was not known, ETS and EES values were converted to an ‘equivalent’ delta-V value using linear regression. Full width crashes were defined as those with an overlap of between 70 and 100 percent of the front of the vehicle, whilst offset crashes were defined as those with an overlap of between 30 and 50 percent. Logistic risk curves were applied to the accident data for the full width and offset overlap configurations, which are shown in Figure 1 and Figure 2.

![Figure 1: Risk of MAIS 2+ injury by delta-V in GIDAS data set (full frontal crash, 70-100% overlap).](image-url)
Figure 2: Risk of MAIS 2+ injury by delta-V in GIDAS data set (offset crash, 30-50% overlap).

The estimation of benefit, using the ‘equal risk at test speed’ assumption described previously, aimed to predict a new risk curve for future vehicles in full width crashes by shifting the risk curve horizontally such that it produced an equal risk to the offset crashes at the corresponding test speed, i.e. it was assumed that the shape of the risk curve was determined by the nature of the crash, whilst the horizontal position was determined by the level of protection that the vehicle will offer at a given impact speed.

The methodology used by Stanzel assumed that delta-V in real-world crashes was 10 percent higher than test speed as a result of rebound. Using this assumption, the risk of sustaining a MAIS 2+ injury in an offset impact at 70.4km/h (10 percent greater than the EuroNCAP test speed of 64 km/h) was found to be 72.6%. The risk curve for the full width crashes was shifted horizontally such that an equal risk of 72.6% corresponded to the proposed test speed of 56km/h, or 61.6km/h when 10 percent was added. This resulted in a shift of 1.4km/h to the right for the injury risk curve for full width impacts, as shown in Figure 3.
The difference between this new injury risk curve for full width impacts and the current one was used to determine the overall benefit of the introduction of a full width test. The calculated benefit, in terms of MAIS 2+ injuries, indicated that the full width test would be expected to reduce the number of occupants sustaining MAIS 2+ injuries by approximately 1.9%, based on the 7079 occupants sustaining MAIS 2+ injuries in the German sample.

In addition, analysis of the data set using EES was undertaken without using the conversion of ETS and EES to delta-V (Figure 4). In this case, it was assumed that the EES was approximately 10 percent lower than the test speed. According to the methodology used, the same risk of MAIS 2+ injury would be expected in an offset crash at an EES relating to a test speed of 64 km/h and a full width crash at an EES relating to a test speed of 58 km/h. As the proposed full width test has a test speed of 56 km/h, it was concluded that there would be no benefit expected.
A further analysis of MAIS 3+ injury undertaken by LAB was also reported, which showed similar results to those described for the use of EES values above (Figure 5). It was expected that there would be no benefit in a full width test at 56 km/h, as an equivalent risk to the offset test would only be seen at a full width test speed of 58 km/h.

In summary, the main conclusion of the Stanzel benefit analysis was that the predicted overall benefit of the introduction of a full width frontal impact test would be ‘marginal’.

### 2.2 Key factors requiring further examination

An initial review of the Stanzel benefit analysis indicated that some key factors required further investigation before the results of the analysis could be accepted as conclusive. The following key factors were investigated:
The sensitivity of the risk curves.

The effect of using different accident data from a different country, such as the UK’s CCIS (Co-operative Crash Injury Study) database.

The effect of estimating the benefit for higher severity injuries, i.e. MAIS 3+ injuries instead of MAIS 2+ injuries.

The investigation of potential confounding factors.

The results of this investigation are reported in this section.

2.2.1 Sensitivity of risk curves

The basis of the Stanzel benefit analysis was the use of logistic regression curves to estimate the probability of an occupant sustaining a MAIS 2+ injury in a frontal impact at a given impact speed. The data sets that were used to calculate these curves contained several outliers at high and low speeds, which may have affected the shape of the risk curves. This was particularly evident when examining the risk curve for the offset crash configuration (Figure 6).

![Figure 6: Risk of MAIS 2+ injury by delta-V in GIDAS data set (offset crash, 30-50% overlap)](image)

Inspection of the probability of MAIS 2+ injury in offset crashes in the German data set showed an unusually high probability of MAIS 2+ injury for vehicles with a very low delta-V. The probability of sustaining a MAIS 2+ injury at a delta-V of approximately 5km/h was approximately 23 percent. This figure seems unrealistically high, especially considering the probabilities of sustaining MAIS 2+ injuries at 10km/h and 15 km/h were significantly lower. The risk curve for this data set appears to be artificially skewed by this high probability at very low speed, which may account for the shape of the curve, which is much ‘shallower’ than the risk curve for the full width crashes (Figure 7). The offset crash data set also contained one outlying case in the 120km/h group which was approximately 30 km/h higher than the next highest value of delta-V.
Figure 7: Comparison of GIDAS risk curves for offset and full width crashes, showing ‘shallower’ curve for offset crashes.

It is expected that the removal of these outliers would change the shape of the risk curve for the offset crashes, which would therefore have implications for the calculation of benefit.

The calculation of the risk curves without converting the recorded values of ETS and EES into delta-V showed a significantly different risk curve shape for the offset crashes, this time being more in line with the shape of the risk curve for full width crashes (Figure 8).

Figure 8: MAIS 2+ injury risk using EES as the severity measure, therefore without conversion of EES and ETS to delta-V.

The significant difference in the shape of this curve for the offset crashes in the previous analysis indicated that there were significant sensitivity issues with this method of calculating benefit.
2.2.2 **Effect of using different accident data (CCIS)**

The Stanzel benefit analysis only used German data from the GIDAS database. In order to check if the conclusions from the Stanzel benefit analysis were relevant for a different country’s accident database, the UK’s CCIS (Co-operative Crash Injury Study) was used to repeat the analysis. The Stanzel benefit analysis used a data set from GIDAS with the following selection criteria:

- Belted front seat occupants of passenger cars
- Frontal crashes
- Primary Direction of Force of 11, 12 or 1 o’clock
- Vehicle manufactured in 1997 or later

The CCIS data set was taken from CCIS Phases 6, 7 & 8, which contained data for accidents that occurred between 1998 and 2007. The following data selection criteria were applied:

- Belted front seat occupants of passenger cars
- Occupant age 12+ to exclude young children in child seats
- Frontal impact (only 1 significant impact)
- All collision partners included
- Primary Direction of Force between 11 and 1 o’clock
- No rollover
- Vehicle registered in 1998 or later
- Known occupant injury
- Known ETS (Estimated Test Speed)

The analysis performed previously by Stanzel using the GIDAS database was repeated using the CCIS data set. The full width crashes were considered to be those with an overlap of 70 to 100 percent, whilst the offset crashes were considered to be those with an overlap of 25 to 55 percent. The offset overlap considered in the CCIS data set was slightly larger than that used in Stanzel’s analysis, where an overlap of 30 to 50 percent was used. This ensured that both the full width and the offset crash configurations had equal band widths of 30 percent.

The likelihood of MAIS 2+ injury in the CCIS data set against ETS was calculated for both full width and offset crashes, using the logistic regression technique. The curves for likelihood of MAIS 2+ injury in the full width and offset crashes are shown in Figure 9 and Figure 10.

It should be noted that the ‘likelihood of injury in the CCIS data set’ is not the same as the risk of injury quoted for the Stanzel analysis with the GIDAS database, because of the way in which data is collected in CCIS. The CCIS database uses a stratified sample which is biased towards fatal and serious crashes, whereby the study attempts to investigate all crashes where fatal and serious injuries are sustained and randomly investigates a number of crashes where slight injuries are sustained, in order to investigate a contracted number of cases per year. The GIDAS database is a statistically correct data set where cases are sampled randomly. Therefore, there will be more cases with injury levels of MAIS 0 (uninjured) and MAIS 1 (slight injury) in the GIDAS data set than in CCIS.

The ‘likelihood of injury in the data set’ describes the likelihood of sustaining an injury of a particular severity, given that the case was in the CCIS database.
Comparison of the CCIS likelihood of injury curves with the risk curves derived for the GIDAS database is shown in Figure 11. This shows the significant difference in the shape of the curves for the offset crashes in the GIDAS and CCIS data sets, giving further weight to the argument that the GIDAS risk curve for offset crashes is skewed by the low speed data, as described in Section 2.2.1. The GIDAS curve is approximately the same shape as the CCIS curve for the full width crashes, although there is a difference in the horizontal position of the curves. When the different crash severity measures and sampling strategies of the CCIS and GIDAS databases are considered, minor differences are expected between the curves. It can be considered that there are no significant differences between the shape of the curves for full width crashes, but the shape of the curves for the
offset crashes are significantly different, even when taking the differences in the databases into account.

![Comparison of risk curves for CCIS and GIDAS data sets.](image)

**Figure 11: Comparison of risk curves for CCIS and GIDAS data sets.**

Following this comparison between the CCIS likelihood of injury curves and the GIDAS injury risk curves, the analysis performed by Stanzel was performed using CCIS data.

In the same way as was described in the Stanzel benefit analysis, a new likelihood of injury curve for ‘future’ vehicles in full width crashes was predicted using the ‘equal risk at test speed’ assumption. However, there were two significant differences in the use of this assumption for the CCIS analysis. These were the value of the assumed test speed for offset crashes and the difference between the calculated value of delta-V (or in this case ETS) in real-world crashes and actual test speed.

In Stanzel’s analysis, it was assumed that all of the cars included in the analysis of offset crashes would have been “NCAPable”, in other words designed to perform well in a EuroNCAP frontal impact 40% offset test at 64 km/h. The risk of injury in these vehicles at 64km/h was used as a target for the maximum potential benefit of introducing the full width test. However, several vehicles that were tested in the first three or four years of EuroNCAP scored poorly (e.g. 2 stars) or were deemed to have the likelihood of life-threatening injury in the test (struck through star). In many of these cars, the dummy injury levels in the EuroNCAP test would have exceeded the maximum limits set in the frontal impact Directive. However, all of these vehicles would have had to have dummy injury levels that were below the limits in the Directive test at 56 km/h. As a result, the test speed for the offset crashes was lowered to 56 km/h for the purposes of the CCIS analysis.

The second difference relates to the difference between calculated value of delta-V (or ETS) and the actual test speed. Stanzel’s analysis assumes that delta-V is typically about 10 percent higher than test speed due to rebound. However, analysis of the actual difference between calculated delta-V and actual delta-V in a crash test with a deformable barrier performed by Lenard et al [2] indicated that the mean underestimation was 5 km/h. Therefore, this value was used for the CCIS analysis.

The prediction of the likelihood of injury curve for ‘future’ vehicles in full width crashes was estimated using the CCIS data set and the assumptions described above (Figure 12).
In an offset deformable barrier test with test speed 56 km/h, the underestimation of test speed by 5 km/h described above gives a value of ETS of 51 km/h. This equates to a likelihood of MAIS 2+ injury in the CCIS data set of 60.7%. Using the ‘equal risk at test speed’ assumption, the likelihood of MAIS 2+ injury in a full width crash in the CCIS data set at the test speed of 56 km/h should be 60.7%, which currently occurs at 48.3 km/h. The underestimation of test speed by 5 km/h means that the risk of 60.7% should occur at an ETS of 51 km/h, which results in a shift of the full width likelihood of injury curve by 2.7 km/h to the right (shown in yellow on the graph above).

This velocity shift was almost twice as much as the shift of 1.4 km/h to the right reported by Stanzel. However, the overall benefit is still likely to be quite low as the actual velocity shift of 2.7 km/h is still quite low.

### 2.2.3 Effect of analysis with MAIS 3+ injury levels

The Stanzel benefit analysis focuses on MAIS 2+ as the measure of injury used to assess the benefit of introducing a full width frontal impact test. However, MAIS 2+ may not be the best measure of life-threatening injury that a future impact test procedure would aim to prevent. Many injuries at AIS 2 level are not life-threatening, some examples of these being concussion, amnesia, sprains or bone fracture. In addition, other analyses of this type are often performed at MAIS 3+ level. Therefore, the analysis was repeated using higher severity MAIS 3+ injury levels.

The likelihood of injury curves were re-calculated for offset and full width crashes using the likelihood of MAIS 3+ injury in the CCIS data set (Figure 13 and Figure 14).
Comparison of the MAIS 2+ and MAIS 3+ likelihood of injury curves showed that, as expected, there was a lower likelihood of MAIS 3+ injury at lower speeds than the MAIS 2+ injury (Figure 15). It also showed that there was little difference in the likelihood of MAIS 3+ injury in full width and offset crash configurations.
The prediction of the likelihood of injury curve for ‘future’ vehicles in full width crashes, based on the methodology used in the Stanzel benefit analysis, is shown in Figure 16.

The likelihood of MAIS 3+ injury curves in the full width crashes and the offset crashes showed the same likelihood of injury at the respective test speeds (56 km/h for both tests, adjusted to 51 km/h on the graph to account for the 5 km/h underestimation of test speed). This result indicated that there could not be any benefit of the full width test for MAIS 3+ injuries according to the methodology.
used by Stanzel, as the likelihood of injury in a full width crash was already equal to the likelihood of injury in an offset crash.

2.2.4 Key influencing factors

2.2.4.1 Confounding factors

Investigation of several potential confounding factors was undertaken using the data from the CCIS data set. Confounding factors are those which are not constant between the data sets being examined, such as occupant age and gender. Differences in the make-up of the data sets with regard to these confounding factors may confuse the overall results, resulting in misleading conclusions. For example, if one of the overlap groups used in this analysis (such as offset or full width crashes) has a large proportion of elderly occupants and the other has a small proportion of elderly occupants, the results could be skewed if elderly occupants are more likely to sustain more severe injuries at lower speeds than younger occupants. Without detailed investigation of these confounding factors the overall results could show that an occupant is more likely to sustain a severe injury in one overlap configuration than the other, but the real reason for this could be the due to occupant age. Therefore, the distribution of the potential confounding factors need to be checked to ensure that similar proportions are observed for the data sets that are being compared.

The potential confounding factors investigated in this analysis were occupant characteristics such as age and gender, collision partners, impact direction, and occupant injury.

Occupant age

Investigation of the age distribution of vehicle occupants in the CCIS data sets was undertaken to check if there were any significant differences that might skew the analysis. The results showed that there was a similar age distribution of ages in both the full width and offset crashes (Figure 17).

![Figure 17: Distribution of age for occupants in full width and offset impacts.](image-url)
**Occupant gender**

The investigation of the distribution of gender of the occupants involved in full width and offset crashes in the CCIS data set showed that there was a similar distribution of males and females in both impact configurations (Figure 18).

![Figure 18: Distribution of gender for occupants in offset and full width impacts.](image)

**Collision partner**

The distribution of collision partners in the full width and offset crash configurations in the CCIS data set was investigated (Figure 19).

![Figure 19: Distribution of collision partner in offset and full width impacts.](image)

This showed that the only significant difference between the distribution of collision partners was that there were no full width impacts with poles/narrow objects. As this was part of the nature of the difference between the impact configurations, i.e. it is not possible to have a full width impact with a...
narrow object, this group was not removed from the analysis. Furthermore, this group was not likely to affect the results of the analysis as the number of cases was very low.

*Primary direction of force*

The distribution of the Primary Direction of Force (PDF) in the full width and offset configurations was investigated (Figure 20). This showed a very similar split between 11, 12 and 1 o’clock in both configurations, with the over 70 percent of cases having a PDF of 12 o’clock.

![Figure 20: Distribution of Primary Direction of Force (PDF) in offset and full width impacts.](image)

*Occupant injuries*

The Stanzel benefit analysis only considered the overall MAIS level of the occupant when estimating the benefit of introducing a full width test. The overall MAIS level does not take into account any variation in the body region injured, so the distribution of the injuries by body region was investigated in order to see if there were any differences between occupants injured in offset and full width accidents.

Comparison of the distribution of AIS 2+ injuries by body region for the offset and full width configurations is shown in Figure 21. This shows some small differences in the injury distribution in the two configurations of less than 10 percent, but no substantial differences. The occupants in full width crashes experienced a slightly higher proportion of AIS 2+ head, thorax, arm and left leg injuries than in offset crashes. The occupants in the offset configuration experienced a slightly higher proportion of AIS 2+ neck and right leg injuries than in full width crashes, with approximately similar proportions of AIS 2+ abdomen, pelvis and surface injuries. Both configurations showed that the thorax was the most frequently injured body region at AIS 2+ level.
However, as stated previously, AIS 2+ injuries include injuries that are not considered to be life-threatening injuries, so the distribution of injuries at AIS 3+ level was investigated (Figure 22). This showed a significant difference in the distribution of injuries for the full width and offset crash configurations. In full width crashes where MAIS 3+ injury occurred, the thorax was the most frequently injured body region, experiencing an AIS 3+ injury in approximately 55 percent of these cases. However, in offset crashes where MAIS 3+ injury occurred, the right leg sustained an AIS 3+ injury the most frequently, in approximately 53 percent of the cases. This highlighted a substantial difference in the injury mechanisms of occupants in the full width and offset crash configurations that is not shown when only considering the overall MAIS level.

Figure 21: Comparison of injury distribution by body region for AIS2+ injuries in offset and full width impacts (1998 on).
Figure 22: Comparison of injury distribution by body region for AIS3+ injuries in offset and full width impacts (1998 on).

The AIS 3+ injury distribution for ‘drivers only’ in the two impact configurations showed similar results to those for all front seat occupants (Figure 23).

Figure 23: Comparison of injury distribution by body region for ‘drivers only’ with AIS3+ injuries in offset and full width impacts (1998 on).

The injury distribution for front seat passengers (FSPs) showed an even higher proportion of AIS 3+ thorax injuries in full width impacts, with lower proportions of leg injuries compared to the driver (Figure 24). However, as there were only six cases of front seat passengers sustaining MAIS 3+ injury...
in offset crashes in the data set, no meaningful analysis could be made regarding the injury distribution for this group.

Figure 24: Comparison of injury distribution by body region for front seat passengers with AIS3+ injuries in offset and full width impacts (1998 on). Note the very low number of offset cases.

In both impact configurations, the most frequently injured body regions at AIS 3+ level when a MAIS 3+ injury is sustained are the thorax and right leg. However, the likelihood of sustaining an AIS 3+ injury in these body regions is quite different for full width and offset crashes. The likelihood of injury curves for AIS 3+ thorax and AIS 3+ leg injury are shown in Figure 25. The likelihood of sustaining an AIS 3+ leg injury in an offset crash is significantly higher than in a full width crash at the same speed, whilst the likelihood of sustaining an AIS 3+ thorax injury in a full width crash is significantly higher than in an offset crash.
This shows that the injury distribution in the offset and full width crash configurations is a significant confounding factor for MAIS 3+ injury severity, although this is not as significant at MAIS 2+ level. The investigation of the injury distribution in the CCIS data set showed that an occupant in an offset crash was most likely to sustain AIS 3+ injuries to the leg, whereas in the full width configuration an occupant was most likely to sustain AIS 3+ thorax injuries.

2.2.4.2 Other influencing factors

Likelihood of injury for occupants of newer cars

The Stanzel benefit analysis defined vehicles as being “state-of-the-art” or “NCAPable” if they were manufactured in 1997 or later. However, these were not necessarily new vehicle designs, or indeed vehicles that would necessarily perform well in the EuroNCAP tests as shown by the results from the early phases of the EuroNCAP testing programme. Therefore, the risk curves for MAIS 2+ and MAIS 3+ injury in newer vehicles (defined as those manufactured in 2000 or later) were compared to those for older vehicles (Figure 26 and Figure 27).
The comparison of the risk curves for older and newer vehicles showed little difference for likelihood of MAIS 2+ injury. There was a slight reduction in likelihood of MAIS 3+ injury in full width crashes in the newer vehicles.
Intrusion

It was expected that the cars in the CCIS data set would experience greater levels of intrusion in offset crashes than in full width crashes at similar speeds, as more energy can be absorbed by a car’s frontal structure in a full width crash, resulting in less energy being absorbed in the compartment and subsequently leading to intrusion. The intrusion levels in full width and offset crashes in the data set were investigated in order to check that this expectation was correct. A comparison of the average intrusion on the occupant’s side of the vehicle against ETS was undertaken for the two crash configurations (Figure 28). Linear regressions of the data showed that the expectation was correct, as the offset crashes exhibited higher levels of intrusion than the full width crashes at corresponding speeds.

![Figure 28: Comparison of intrusion on occupant side (cm) against ETS (km/h) for full width and offset overlaps, showing higher levels of intrusion in offset impacts.](image)

It has been shown that in full width crashes there is a lower likelihood of intrusion compared to offset crashes at equivalent speed. Less intrusion in full width impacts is likely to mean less chance of the occupant contacting the interior of the vehicle, which suggests that a high proportion of the injuries to the thorax and abdomen for occupants in full width crashes are induced by the restraint system. The introduction of the proposed full width frontal impact test would encourage the improvement of restraint systems to cope more effectively with the higher deceleration of a full width crash. The improvement of restraint systems in general is likely to help reduce or even prevent restraint-induced injuries in full width crashes, and the improvement in restraint systems would also be expected to have benefit in other crash configurations.

2.3 Conclusions

The benefit analysis performed by Stanzel concluded that the benefit of introducing a full width frontal impact test procedure, in terms of occupant injury, was ‘marginal’. A review of this analysis indicated some potential issues that may have had an effect on this conclusion. The shape of the MAIS 2+ injury risk curve for offset crashes in the Stanzel benefit analysis was much shallower than the corresponding curve for full width crashes, indicating a higher risk of MAIS 2+ injury at low speeds and a lower risk of MAIS 2+ injury at higher speeds. This was believed to be
the result of the risk curve being skewed by a high risk of MAIS 2+ injury at very low speed (around 5 km/h), data which seems unrealistic for belted occupants. In addition, the shape of the risk curve changed considerably when the severity measure was changed to EES, in other words without the calculation of ‘equivalent’ delta-V values based on conversion from ETS and EES values. This indicated that the risk curves were very sensitive to changes in the data, and the curve that has been used to calculate the final benefit appears to be unrealistic. The benefit analysis is based on the comparison between the risk curve for the offset crashes and the risk curve for the full width crashes, so if the offset risk curve is skewed then this could have a significant effect on the predicted benefit.

The proposed definition of the potential benefit of a full width frontal impact test was limited by two assumptions. The first was that the risk of injury in a full width crash could only ever match the risk of injury in an offset crash, and the second was that there would only be benefit for occupants in full width impacts. These assumptions do not allow for the possibility that the risk of injury in a full width impact could reduce to a level below that seen in offset crashes, nor do they take into account that the introduction of a full width test is likely to have some benefit for occupants in other crash configurations.

The Stanzel benefit analysis only used German data from the GIDAS database. In order to check if the conclusions from the Stanzel benefit analysis were relevant for a different accident database based in a different country, the UK’s CCIS (Co-operative Crash Injury Study) was used to repeat the analysis. This showed that there was little difference in the likelihood of injury in the CCIS data set for full width and offset crashes, either at MAIS 2+ level or at the more severe MAIS 3+ level. This indicated that there was little or no benefit in the introduction of a full width frontal impact test according to the methodology proposed by Stanzel.

Several potential confounding factors were investigated, to check if there were any factors which may confuse the overall results, resulting in misleading conclusions. The following factors were investigated:

- Occupant characteristics (age and gender)
- Distribution of collision partners and PDF (Primary Direction of Force)
- Occupant injury

Of these potential confounding factors, the analysis of occupant injury appeared to be the most significant. Whilst there were no substantial differences between the injury distributions at MAIS 2+ level, there was a substantially different distribution of injuries between the offset and full width crash configurations at MAIS 3+ level. A higher proportion of thorax injuries were observed in full width crashes than offset crashes, whereas there was a higher proportion of leg injury in offset crashes. This difference in injury distribution at MAIS 3+ level would mean that using the Stanzel methodology to calculate benefit at higher injury severity levels is likely to lead to inaccurate results.

In summary, the main conclusions were:

- The results of Stanzel’s benefit analysis were unreliable due to the sensitivity of the risk curves used as well as the limiting effect of the assumptions that there would only be benefit in full width impacts and only up to the current level of performance in offset impacts.
- In order to be in line with other analyses of this type a higher severity injury measure such as MAIS 3+ should be used, whereas the Stanzel analysis only used MAIS 2+. However, the confounding effect of body injury distribution at MAIS 3+ level means that this is not possible.
- It was concluded that a different methodology was required in order to calculate the benefit for GB.
3 Benefit Analysis for GB

The second objective of this work was to calculate the benefit from the introduction of a full width frontal impact test using GB data. Following the review of the benefit analysis performed by Stanzel, it was concluded that a different methodology was required in order to assess the benefit.

This section of the report describes the methodology used to calculate the benefit for the introduction of a full width frontal impact test using GB data. Estimates of benefit in terms of the proportional reduction in fatal and serious injuries were calculated using the CCIS data set, which were then scaled up to a national level using the STATS19 database.

3.1 Methodology and assumptions

In order to calculate the benefit from the introduction of a full width frontal impact test procedure, a methodology was developed that focused on the specific benefit that a full width test might be expected to achieve. The full width test produces a higher peak deceleration in a car than the offset deformable barrier test, meaning that it is a more severe test for the restraint systems in the car. The assumption is that the introduction of a full width test will encourage improved restraint systems, which will in turn reduce restraint-induced injury.

In this analysis, it was assumed that the main body regions where a reduction in restraint-induced injury would be observed would be the thorax and abdomen, areas where the seat belt webbing from a three-point belt normally loads. The analysis assumed that thorax and abdomen injuries would be reduced in a ‘future’ car meeting the requirements of a new full width frontal impact test. Restraint-induced thorax and abdomen injuries were assumed to be those which occurred in frontal impacts where there was little or no intrusion.

Firstly, a target population that could benefit from the introduction of a full width frontal impact test was derived from the entire CCIS database. In this target population, individual casualties were assessed in terms of both the overall MAIS level and the AIS injury levels sustained by the thorax and abdomen. From this, ‘new’ MAIS levels were calculated for each case by reducing thorax and abdomen AIS levels, and the distribution of these ‘new’ MAIS levels was compared with the original MAIS distribution to give an estimated benefit in terms of reduction in MAIS. As the GB national accident data only records injury levels in terms of the police casualty severity measures (fatal, serious, slight and uninjured), the benefit in these terms was calculated. This was done by calculating the percentage distribution of fatal, serious and slight injuries for each MAIS level in the original target population, and using these figures to transform MAIS benefit into police severity benefit. The last step involved the scaling of the CCIS benefit up to a national level for GB by using the STATS19 accident statistics, which required the calculation of an equivalent target population in STATS19 to that used in CCIS. From this, a national benefit for GB for the introduction of a full width frontal impact test was derived.

In summary, the methodology used in this benefit analysis consisted of three parts:

- Using the CCIS data set, estimate the benefit in terms of reduction in injury (MAIS) for each individual casualty within the target population.
- Transform benefit calculated in terms of MAIS reduction to the police casualty severity measures (fatal, serious, slight and uninjured) in order to give benefit in these terms.
- Scale to national level in GB using the STATS19 statistics, using benefit proportions calculated from the CCIS data set.

Four models were used to estimate the benefit in terms of MAIS, these are described in more detail in Section 3.2.1.
3.2 Target population

The CCIS data set used for the calculation of benefit was taken from CCIS Phases 6, 7 & 8, which comprised accidents that occurred between 1998 and 2007. The same data selection criteria as were used in the review of the Stanzel benefit analysis were applied:

- Belted front seat occupants of passenger cars
- Occupant age 12+ to exclude young children in child seats
- Frontal impact (only 1 significant impact)
- All collision partners included
- Primary Direction of Force between 11 and 1 o’clock
- No rollover
- Vehicle manufactured in 1998 or later
- Known occupant injury
- Known ETS (Estimated Test Speed)

This produced a data set containing 1869 occupants. The distribution of MAIS injury levels in the data set is shown in Table 1.

<table>
<thead>
<tr>
<th>MAIS</th>
<th>Number of Occupants</th>
<th>% of occupants in data set</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>296</td>
<td>15.8</td>
</tr>
<tr>
<td>1</td>
<td>1084</td>
<td>58.0</td>
</tr>
<tr>
<td>2</td>
<td>280</td>
<td>15.0</td>
</tr>
<tr>
<td>3</td>
<td>135</td>
<td>7.2</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>2.0</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>1.9</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>1869</td>
<td>100</td>
</tr>
</tbody>
</table>

3.2.1 Calculation of benefit for removal of thorax and abdomen injuries

The assumption made for the calculation of benefit was that the introduction of a full width frontal impact test would improve the restraint systems in cars, thereby reducing thorax and abdomen injury in frontal crashes.

Four models were used to investigate the potential benefit of a full width frontal impact test. These were as follows:

- **Model 1**: Original data set. This model assumes that all serious thorax and abdomen injuries would be reduced in severity by the introduction of a full width frontal impact test. It was assumed that thorax and abdomen injuries would be reduced by a maximum of 2 AIS levels, with no injuries being reduced to a level lower than AIS 1. For example, an AIS 5 thorax or abdomen injury would only be reduced to AIS 3, an AIS 2 would only reduce to AIS 1 and there would be no reduction for AIS 1 injuries. The MAIS injury level would then be recalculated as the highest AIS level in all body regions after reduction of thorax and abdomen injury.
- **Model 2:** As Model 1, with ETS ≤ 56 km/h. This model assumes that there will only be benefit from introduction of the full width test up to the proposed test speed of 56 km/h. Therefore, this model assumes the reduction in severity of all thorax and abdomen injuries in crashes up to and including 56 km/h.

- **Model 3:** As Model 2, with less than 5 cm intrusion present on the occupant’s side of the vehicle. This model assumed that there could only be benefit from the improvement of the restraint system in cases where the thorax and abdomen did not come into contact with the interior of the vehicle. This model assumes that all thorax and abdomen injury in vehicles without intrusion would be expected to be restraint-induced.

- **Model 4:** As Model 3, but excluding occupants over 65 years of age. Kent et al [3] showed that restraint-induced thoracic injury in frontal impacts is heavily dependent on age, with a 70-year-old having significantly higher probability of sustaining an injury due to chest deflection than a 30-year-old (Figure 29). In this benefit analysis, elderly occupants were considered to be more likely to sustain serious restraint-induced injury and therefore might not fully benefit from any improvement of the restraint system. This model was expected to provide the most realistic benefit of the four models.

![Figure 29: Comparison of probability of serious chest injury (multiple rib fracture) for 30-year-old and 70-year-old.](image)

The number of occupants in the data sets for each of the four models is shown in Table 2.

**Table 2: Number of occupants in data set for the four benefit models.**

<table>
<thead>
<tr>
<th>Sampling Criteria</th>
<th>Number of occupants</th>
<th>Percentage of original data set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: Original data set</td>
<td>1869</td>
<td>100.0</td>
</tr>
<tr>
<td>Model 2: As Model 1 with ETS ≤ 56 km/h</td>
<td>1812</td>
<td>96.7</td>
</tr>
<tr>
<td>Model 3: As Model 2 with Intrusion on occupant side &lt; 5 cm</td>
<td>1594</td>
<td>85.3</td>
</tr>
<tr>
<td>Model 4: As Model 3 with Occupant age ≤ 65</td>
<td>1342</td>
<td>71.8</td>
</tr>
</tbody>
</table>
The calculation of the new MAIS levels for the occupants in the data set was carried out for the four models described above. The new MAIS distribution included the unchanged MAIS levels for cases which were excluded by the assumptions in the models, in order to describe the benefit in terms of the whole data set.

The change in MAIS distribution for the four models is shown in Table 3, Table 4, Table 5 and Table 6.

Table 3: Change in MAIS levels for entire CCIS data set using Model 1.

<table>
<thead>
<tr>
<th>MAIS</th>
<th>Original data set (No. of occupants)</th>
<th>Data set with applied benefit (Model 1) (No. of occupants)</th>
<th>Change (No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>296</td>
<td>296</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1084</td>
<td>1201</td>
<td>+117</td>
</tr>
<tr>
<td>2</td>
<td>280</td>
<td>211</td>
<td>-69</td>
</tr>
<tr>
<td>3</td>
<td>135</td>
<td>133</td>
<td>-2</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>17</td>
<td>-20</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>10</td>
<td>-25</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Total</td>
<td>1869</td>
<td>1869</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4: Change in MAIS levels for CCIS data set using Model 2 (ETS ≤ 56 km/h).

<table>
<thead>
<tr>
<th>MAIS</th>
<th>Original data set (No. of occupants)</th>
<th>Data set with applied benefit (Model 2) (No. of occupants)</th>
<th>Change (No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>296</td>
<td>296</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1084</td>
<td>1200</td>
<td>+116</td>
</tr>
<tr>
<td>2</td>
<td>280</td>
<td>209</td>
<td>-71</td>
</tr>
<tr>
<td>3</td>
<td>135</td>
<td>122</td>
<td>-13</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>19</td>
<td>-18</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>21</td>
<td>-14</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1869</td>
<td>1869</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 5: Change in MAIS levels for CCIS data set using Model 3 (Intrusion ≤ 5 cm).

<table>
<thead>
<tr>
<th>MAIS</th>
<th>Original data set (No. of occupants)</th>
<th>Data set with applied benefit (Model 3) (No. of occupants)</th>
<th>Change (No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>296</td>
<td>296</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1084</td>
<td>1195</td>
<td>+111</td>
</tr>
<tr>
<td>2</td>
<td>280</td>
<td>206</td>
<td>-74</td>
</tr>
<tr>
<td>3</td>
<td>135</td>
<td>114</td>
<td>-21</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>26</td>
<td>-11</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>30</td>
<td>-5</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1869</td>
<td>1869</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 6: Change in MAIS levels for CCIS data set using Model 4 (Age ≤ 65).

<table>
<thead>
<tr>
<th>MAIS</th>
<th>Original data set (No. of occupants)</th>
<th>Data set with applied benefit (Model 4) (No. of occupants)</th>
<th>Change (No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>296</td>
<td>296</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1084</td>
<td>1174</td>
<td>+90</td>
</tr>
<tr>
<td>2</td>
<td>280</td>
<td>219</td>
<td>-61</td>
</tr>
<tr>
<td>3</td>
<td>135</td>
<td>115</td>
<td>-20</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>29</td>
<td>-8</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>34</td>
<td>-1</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1869</td>
<td>1869</td>
<td>-</td>
</tr>
</tbody>
</table>

3.2.2 Transformation to police severity

In order to establish a benefit in terms of police casualty severity measures, the correlation between fatal and serious severity in the CCIS data set and MAIS was established (Table 7). This would enable the estimation of fatal and serious injury based on the reduction in MAIS level achieved by removing specific injuries.
Table 7: Percentage of police casualty severity measures for each MAIS level.

<table>
<thead>
<tr>
<th>MAIS</th>
<th>Fatal (%)</th>
<th>Serious (%)</th>
<th>Slight (%)</th>
<th>Uninjured (%)</th>
<th>Not known (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>1.4</td>
<td>1.0</td>
<td>95.9</td>
<td>1.7</td>
</tr>
<tr>
<td>1</td>
<td>0.1</td>
<td>9.2</td>
<td>90.2</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>97.1</td>
<td>2.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>5.2</td>
<td>94.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>48.6</td>
<td>51.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>85.7</td>
<td>14.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>6</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The calculated benefit in the CCIS data set in terms of the police casualty severity measures for the four benefit models, calculated using the transfer function in Table 7, is shown in Table 8. This shows that the final model (Model 4) predicts a reduction in fatalities in the CCIS data set of 10 percent, with a reduction in serious injuries of 14 percent.

Table 8: Estimated benefit in CCIS in terms of police casualty severity measures for Models 1-4.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Original CCIS data set (No. of occupants)</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change (No.)</td>
<td>Change (%)</td>
<td>Change (No.)</td>
<td>Change (%)</td>
<td>Change (No.)</td>
</tr>
<tr>
<td>Fatal</td>
<td>59</td>
<td>-32.4</td>
<td>-54.9</td>
<td>-21.6</td>
<td>-36.6</td>
</tr>
<tr>
<td>Serious</td>
<td>528</td>
<td>-72.0</td>
<td>-13.6</td>
<td>-81.8</td>
<td>-15.5</td>
</tr>
<tr>
<td>Slight</td>
<td>988</td>
<td>+103.8</td>
<td>+10.5</td>
<td>+102.9</td>
<td>+10.4</td>
</tr>
<tr>
<td>Uninjured</td>
<td>285</td>
<td>+0.1</td>
<td>0.0</td>
<td>+0.1</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The difference in predicted benefit between Model 3 and Model 4 should be noted, as this shows the large effect of introducing the assumption that no benefit would be expected for occupants over 65 years of age. Excluding these ‘elderly’ occupants has almost halved the predicted benefit for reducing fatalities. This indicated that elderly occupants over 65 years of age make up a significant proportion of fatally injured car occupants in crashes below 56 km/h where there is little compartment intrusion, where the injuries are to the thorax or abdomen and are most likely restraint-induced.

3.2.3 Predicted GB benefit

To calculate the predicted GB benefit, the proportional benefit calculated from analysis of the CCIS data was scaled using the STATS19 national accident statistics. In order to do this, the target population in CCIS was used to predict scaling factors that would allow an equivalent target population in the STATS19 database to be calculated. These scaling factors were derived to remove cases that were not in the CCIS target population from the STATS19 target population. For example, the CCIS target population excluded unbelted occupants, whereas this is not recorded in STATS19. The percentage of fatal and serious casualties who were wearing a seatbelt in the CCIS database was calculated and this percentage was used to define the number of belted occupants in the STATS19
database. The overall scaling factors consisted of several variables and were used to calculate the overall GB benefit with the CCIS benefit.

In order to estimate the target population in STATS19, the equivalent percentage of the total casualties relating to the CCIS target population was estimated.

In the CCIS database there are 16,444 occupants, of which 4,901 were killed or seriously injured (KSI). Of this number of KSI casualties, 2,727 were involved in frontal impacts – 369 killed and 2,358 seriously injured. These figures represent all KSI in frontal impacts in the CCIS data set. In order to be able to scale up to national level, a percentage of these figures for killed and seriously injured occupants was calculated to take into account the CCIS selection criteria (Table 9).

**Table 9: Calculation of scaling factors to make CCIS compatible with STATS19.**

<table>
<thead>
<tr>
<th></th>
<th>Killed (No. of occupants)</th>
<th>Serious (No. of occupants)</th>
<th>All KSI (No. of occupants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front impact in CCIS</td>
<td>369</td>
<td>2358</td>
<td>2727</td>
</tr>
<tr>
<td>No rollover, PDF 11-1 0’clock, significant impact to front of vehicle</td>
<td>268</td>
<td>1921</td>
<td>2189</td>
</tr>
<tr>
<td>Front row occupants</td>
<td>239</td>
<td>1698</td>
<td>1937</td>
</tr>
<tr>
<td>Seat belt use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used</td>
<td>160</td>
<td>1288</td>
<td>1448</td>
</tr>
<tr>
<td>Not used</td>
<td>52</td>
<td>247</td>
<td>299</td>
</tr>
<tr>
<td>Not known</td>
<td>27</td>
<td>163</td>
<td>190</td>
</tr>
<tr>
<td>No of belted front row occupants in data set (known belted + proportion of unknown)</td>
<td>180</td>
<td>1425</td>
<td>1605</td>
</tr>
<tr>
<td>Percentage of data set w.r.t. all frontal impacts in CCIS (Scaling factor)</td>
<td>48.8%</td>
<td>60.4%</td>
<td>-</td>
</tr>
</tbody>
</table>

The scaling factor was applied to all KSI casualties in frontal crashes in the STATS19 database, averaged over 5 years between 2002 and 2006 (Table 10).

**Table 10: Average casualties in STATS19 (2002-2006).**

<table>
<thead>
<tr>
<th>Point of impact on vehicle</th>
<th>Fatal</th>
<th>Serious</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>36</td>
<td>266</td>
</tr>
<tr>
<td>Front</td>
<td>963</td>
<td>9614</td>
</tr>
<tr>
<td>Back</td>
<td>68</td>
<td>1032</td>
</tr>
<tr>
<td>Sides</td>
<td>625</td>
<td>3527</td>
</tr>
<tr>
<td>Rest</td>
<td>3</td>
<td>73</td>
</tr>
<tr>
<td>Total</td>
<td>1695</td>
<td>14512</td>
</tr>
</tbody>
</table>
Using the numbers in Table 9, Table 10 and the percentage reduction in casualties calculated from Model 4 of the CCIS study in Table 8, the total benefit was calculated. This is summarised in Table 11 below.

### Table 11: Annual reduction in casualties predicted.

<table>
<thead>
<tr>
<th></th>
<th>Fatalities</th>
<th>Serious casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original Number of Casualties</td>
<td>Reduction (No.)</td>
</tr>
<tr>
<td>Model 1</td>
<td>1695</td>
<td>258</td>
</tr>
<tr>
<td>Model 2</td>
<td>1695</td>
<td>172</td>
</tr>
<tr>
<td>Model 3</td>
<td>1695</td>
<td>87</td>
</tr>
<tr>
<td>Model 4</td>
<td>1695</td>
<td>47</td>
</tr>
</tbody>
</table>

The results show that in Model 4, which is considered to be the most realistic model, the predicted benefit for the introduction of a full width frontal impact test would reduce fatalities by between 2 and 3 percent and serious casualties by between 5 and 6 percent.

This was a greater benefit than was estimated in the Stanzel benefit analysis, where a reduction of approximately 1.9 percent of MAIS 2+ injuries was predicted.

### 3.3 Discussion

The benefit calculated for GB, which indicates a reduction in fatal injuries of between 2 and 3 percent and a reduction in serious injuries of between 5 and 6 percent, is a first estimate based on several assumptions. The first assumption is that the high peak deceleration in a full width test will encourage improved restraint systems, which will in turn reduce restraint-induced injury. It was further assumed that the introduction of a full width frontal impact test will reduce restraint-induced thorax and abdomen injuries in frontal crashes up to the proposed test speed of 56 km/h, for occupants under 65 years of age and where little or no compartment intrusion is present. It should be noted that the benefit has a considerable tolerance which is dependent on the performance limits that are set in the proposed test.

An interesting finding in this benefit analysis was that the age of the occupants was a significant factor. The model used to calculate the benefit above excluded occupants over the age of 65. However, the calculated benefit for reduction in fatalities when including these older occupants was almost twice as high (approximately 5 percent). This indicated that a significant number of elderly occupants sustain fatal injuries to the thorax or abdomen in crashes below 56 km/h where there is little compartment intrusion, where the injuries are most likely restraint-induced. It should be noted that if these elderly occupants could be better protected in a vehicle, for example using ‘smart’ restraint systems that could take into account an occupant’s age, then the predicted benefit for introducing a full width test could be substantially increased.

### 3.4 Conclusions

In order to calculate the benefit from the introduction of a full width frontal impact test procedure, a methodology was developed that focused on the specific benefit that a full width test might be expected to achieve. The assumption was that the introduction of a full width test will encourage improved restraint systems, which will in turn reduce restraint-induced injury. It was considered that the main body regions where a reduction in restraint-induced injury would be observed would be the...
Thorax and abdomen, areas where the seat belt webbing from a three-point belt is normally routed. These body regions are also unlikely to sustain contact-induced injuries in a frontal crash unless there are significant levels of intrusion in the occupant compartment. Therefore, the benefit from the introduction of a full width test was estimated by assuming reduction of thorax and abdomen injuries under certain impact conditions. These conditions were described in four benefit models.

The model that was considered to be the most realistic was Model 4. The criteria for the benefit for this model were as follows:

- ETS \( \leq 56 \text{ km/h} \)
- Compartment intrusion on occupant’s side of the vehicle < 5 cm
- Occupant age \( \leq 65 \) years old.

The benefit for GB showed that, for Model 4, the introduction of a full width frontal impact test would be expected to reduce annual fatalities in GB by 2 to 3 percent (approximately 47 occupants) and serious casualties by 5 to 6 percent (approximately 813 occupants). This is a significant benefit that is greater than was estimated in the Stanzel benefit analysis.

Restricting the occupant age to 65 in Model 4 resulted in a significant reduction in predicted benefit compared to Model 3, where elderly occupants were included in the calculated benefit. This indicated that a significant number of elderly occupants sustained serious and fatal restraint-induced thorax and abdomen injury. If these elderly occupants could be better protected in a vehicle, for example using ‘smart’ restraint systems that could take into account an occupant’s age, then the predicted benefit for introducing a full width test could be substantially increased.

It should be noted that the predicted benefit for GB given above is a first estimate, and this has a considerable tolerance that depends on the precise performance limits that are eventually chosen for the full width frontal impact test.
4 Summary of Conclusions

4.1 Review of Stanzel benefit analysis

The benefit analysis performed by Stanzel concluded that the benefit of introducing a full width frontal impact test procedure, in terms of occupant injury, was ‘marginal’. A review of this analysis indicated some potential issues that may have had an effect on this conclusion.

The shape of the MAIS 2+ injury risk curve for offset crashes in the Stanzel benefit analysis was much shallower than the corresponding curve for full width crashes, indicating a higher risk of MAIS 2+ injury at low speeds and a lower risk of MAIS 2+ injury at higher speeds. This was believed to be the result of the risk curve being skewed by a high risk of MAIS 2+ injury at very low speed (around 5 km/h), data which seems unrealistic for belted occupants. In addition, the shape of the risk curve changed considerably when the severity measure was changed to EES, in other words without the calculation of ‘equivalent’ delta-V values based on conversion from ETS and EES values. This indicated that the risk curves were very sensitive to changes in the data, and the curve that has been used to calculate the final benefit appears to be unrealistic. The benefit analysis is based on the comparison between the risk curve for the offset crashes and the risk curve for the full width crashes, so if the offset risk curve is skewed then this could have a significant effect on the predicted benefit.

The proposed definition of the potential benefit of a full width frontal impact test was limited by two assumptions. The first was that the risk of injury in a full width crash could only ever match the risk of injury in an offset crash, and the second was that there would only be benefit for occupants in full width impacts. These assumptions do not allow for the possibility that the risk of injury in a full width impact could reduce to a level below that seen in offset crashes, nor do they take into account that the introduction of a full width test is likely to have some benefit for occupants in other crash configurations.

The Stanzel benefit analysis only used German data from the GIDAS database. In order to check if the conclusions from the Stanzel benefit analysis were relevant for a different accident database based in a different country, the UK’s CCIS (Co-operative Crash Injury Study) was used to repeat the analysis. This showed that there was little difference in the likelihood of injury in the CCIS data set for full width and offset crashes, either at MAIS 2+ level or at the more severe MAIS 3+ level. This indicated that there was little or no benefit in the introduction of a full width frontal impact test according to the methodology proposed by Stanzel.

Several potential confounding factors were investigated, to check if there were any factors which may confuse the overall results, resulting in misleading conclusions. The following factors were investigated:

- Occupant characteristics (age and gender)
- Distribution of collision partners and PDF (Primary Direction of Force)
- Occupant injury

Of these potential confounding factors, the analysis of occupant injury appeared to be the most significant. Whilst there were no substantial differences between the injury distributions at MAIS 2+ level, there was a substantially different distribution of injuries between the offset and full width crash configurations at MAIS 3+ level. A higher proportion of thorax injuries were observed in full width crashes than offset crashes, whereas there was a higher proportion of leg injury in offset crashes. This difference in injury distribution at MAIS 3+ level would mean that using the Stanzel methodology to calculate benefit at higher injury severity levels is likely to lead to inaccurate results.

In summary, the main conclusions were:

- The results of Stanzel’s benefit analysis were unreliable due to the sensitivity of the risk curves used as well as the limiting effect of the assumptions that there would only be benefit in full width impacts and only up to the current level of performance in offset impacts.
In order to be in line with other analyses of this type a higher severity injury measure such as MAIS 3+ should be used, whereas the Stanzel analysis only used MAIS 2+. However, the confounding effect of body injury distribution at MAIS 3+ level means that this is not possible.

It was concluded that a different methodology was required in order to calculate the benefit for GB.

4.2 Benefit analysis for GB

In order to calculate the benefit from the introduction of a full width frontal impact test procedure, a methodology was developed that focused on the specific benefit that a full width test might be expected to achieve. The assumption was that the introduction of a full width test will encourage improved restraint systems, which will in turn reduce restraint-induced injury. It was considered that the main body regions where a reduction in restraint-induced injury would be observed would be the thorax and abdomen, areas where the seat belt webbing from a three-point belt is normally routed. These body regions are also unlikely to sustain contact-induced injuries in a frontal crash unless there are significant levels of intrusion in the occupant compartment. Therefore, the benefit from the introduction of a full width test was estimated by assuming reduction of thorax and abdomen injuries under certain impact conditions. These conditions were described in four benefit models.

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It should be noted that the predicted benefit for GB given above is a first estimate, and this has a considerable tolerance that depends on the precise performance limits that are eventually chosen for the full width frontal impact test.
5 Recommendations

There were two recommendations for further work following on from this work:

- Refine the benefit analysis to understand effect of performance limits in a proposed full width frontal impact test:

  The benefit analysis undertaken for GB for the introduction of a full width frontal impact test showed that there would be a significant benefit of the order of 2 to 3 percent of fatalities and 5 to 6 percent of serious casualties. This calculated benefit is a first estimate, which has a considerable tolerance which is dependent on the precise performance limits that are eventually chosen for the full width frontal impact test. It is recommended that the analysis is refined in order to estimate the effect that changing the performance limits in the test will have on the benefit. It is expected that this will help to set performance limits in a proposed full width test that will encourage the improvement of restraint systems in vehicles.

- Investigation of injuries to elderly occupants in crashes:

  The predicted benefit for GB calculated in this analysis used a benefit model that excluded occupants over the age of 65. The inclusion of the occupants over 65 in the benefit analysis showed a significantly higher benefit, indicating that a significant number of elderly occupants sustained serious and fatal restraint-induced thorax and abdomen injury in frontal crashes. This was most likely due to the higher susceptibility to serious injury of elderly occupants compared to younger occupants as a result of factors such as reduced bone strength. It is recommended that further work is undertaken to investigate the injuries sustained by elderly occupants, in order to better understand the mechanisms of injury and potential ways to better protect this occupant group.
References

1. Stanzel, M. (2006) APROSYS Analysis on Car Accidents with Respect to Advanced Front Impact and Compatibility (Request from SP1.2 to SP8.3). AP-SP8.3-D8.3.2.


Acknowledgements

This report uses accident data from the United Kingdom Co-operative Crash Injury Study (CCIS) collected during the period 1998 to 2007.

Currently CCIS is managed by TRL Limited, on behalf of the United Kingdom Department for Transport (DfT) (Transport Technology and Standards Division) who fund the project along with Autoliv, Ford Motor Company, Nissan Motor Company and Toyota Motor Europe. Previous sponsors of CCIS have included, Daimler Chrysler, LAB, Rover Group Ltd, Visteon, Volvo Car Corporation, Daewoo Motor Company Ltd and Honda R&D Europe (UK) Ltd.

Data was collected by teams from the Birmingham Automotive Safety Centre of the University of Birmingham; the Vehicle Safety Research Centre at Loughborough University; TRL Limited and the Vehicle & Operator Services Agency of the DfT

Further information on CCIS can be found at http://www.ukccis.org
Benefit analysis for the introduction of a Full Width Frontal Impact Test

The APROSYS integrated project on Advanced Protection Systems is an EC 6th Framework project focusing on scientific and technological development in the field of vehicle passive safety. APROSYS sub-project 1 (SP1) is titled ‘Car Accidents’, and within this is work package 1.2 (WP1.2) titled ‘Advanced Frontal Impact’. The aim of WP1.2 is to develop and evaluate a full width high deceleration frontal impact crash test suitable for regulatory application in Europe and to perform associated cost benefit analysis.

A benefit analysis performed for WP1.2 as part of APROSYS SP8.3, using the GIDAS (German In-Depth Accident Study) database, predicted a ‘marginal’ benefit for the introduction of a full width frontal impact test, estimating a reduction in MAIS 2+ injuries of approximately 1.9 percent.

In this report a critical review of the benefit analysis was performed. It found that some key factors did not appear to have been investigated, and that the results were unreliable. A different methodology was used to calculate the benefit for Great Britain (GB), using the CCIS (Co-operative Crash Injury Study) database and STATS19 national accident statistics. This calculated a significant benefit for the introduction of the full width test which was greater than the previous benefit analysis.

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