INFLUENCE OF IMPACT TYPE AND RESTRAINT SYSTEM TRIGGERING TIME ON INJURY SEVERITY IN FRONTAL IMPACT CRASHES

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ABSTRACT

The safety performance of cars is evaluated using standard tests. These standard tests are normally performed with full overlap or 40% overlap from the corner in different speed ranges. Analysis of accident data indicated that the injury severity of car occupants that were involved in accidents that are different compared to the standard tests (e.g., central pole impact) is considerably higher than for those that are similar to the standard tests. One of the discussed possible reasons for this observation is that the restraint system triggering might not be appropriate for these situations.

The combination of NASS CDS data with the NASS EDR data allows to analyse the accident circumstances, the restraint system triggering times and the injury situation in frontal impact accidents. The result of this analysis is a grouping of accident situations with corresponding injury severities and restraint system triggering times. These groups are rechecked using the GIDAS data to confirm the influence of the accident circumstances on the injury severity, as restraint system triggering time is not available in the GIDAS data sample.

The restraint system trigger time depends on several factors (e.g., delta-v, impact configuration (e.g., involving both long members, only one long member or no long member), impact angle etc.). While most of the differences appear to be sensible for optimal protection (e.g., at higher delta-v the airbag is needed earlier) the differences for the different impact configuration appears to be critical with respect to injury severity levels of the frontal occupants.

The shown correlation between crash configuration, restraint system triggering time and injury severity does not necessarily mean that there is a causative relation between triggering delay and increased injury severity. However, it is likely that there is a causative relation.

INTRODUCTION

For the protection of car occupants the design of the vehicle structures, the restraint system that is composed of seat, bolster, belt system (including pretensioners and load limiters) and airbags as well as the appropriate timing of the active restraint system components (e.g., pretensioner and airbag) are important. The occupant protection system is assessed by standard tests (e.g., vehicle homologation and NCAP programmes). Although almost all cars are performing excellent in these standard tests, it might happen that individual cars are performing worse in real world conditions.

Reichert et al. [Reichert 2013] analysed thoracic and abdominal injury risks in NASS frontal impact accidents without front rail involvement (impact location between the rails to be more precise). While they observed an increased injury risk in the analysed accidents they were unable to replicate the increased injury risk in FE simulations. However, they used US NCAP trigger times for the restraint system triggering which might be the main cause for failing.

During the EU funded FIMCAR project airbag trigger times were analysed in order to define a frontal impact test procedure that is more representative of real world accidents than the Full Width Rigid Barrier (FWRB). For some cars considerably late restraint system triggering was observed in Full Width Deformable Barrier tests (FWDB) with important influence on the dummy readings [Johannsen 2012, Johannsen 2013a, Johannsen 2013b], see Figure 1 as an example.
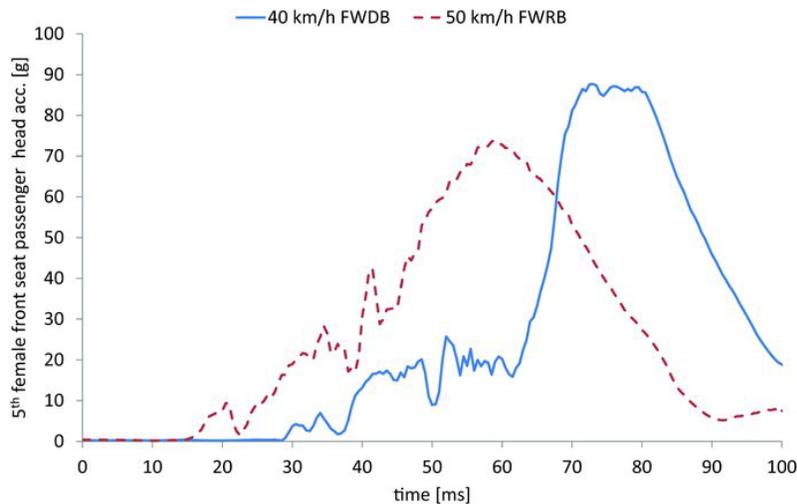
Figure 1. *(a) Late air bag deployment in 40 km/h FWDB test and its consequences for head acceleration. (b) At approximately 30 ms the air bag starts to deploy and (c) at approximately 50 ms the head contacts the deploying air bag [Johannsen 2013a].*

In a physical reconstruction of a real world accident (approx. 35 km/h against a small object between the rails) the airbag was fired at approx. 90 ms by the ECU resulting in a contact between deploying airbag and the occupant in forward movement, see Figure 2 (note: in the original accident a rear facing CRS was positioned at the front passenger seat and the reconstruction was repeated to analyse the consequences for adults).

| approx. 50 ms: occupant starts to move forward | approx. 90 ms: front passenger airbag deploys | approx. 100 ms: airbag hits forward moving occupant |

Figure 2. Front seat passenger airbag deployment in an accident reconstruction.

In accident studies it is normally not possible to assess the restraint system firing time due to missing data insight into the control units. So it is normally only possible to assess whether or not an active restraint system was fired at all. The US NASS EDR data (Event Data Recorder) [Da Silva 2008; Dalmotas 2009; Gabler 2008] allows to also consider the firing time as it is normally recorded in the data sets.

METHOD

For the EDR data analysis NASS CDS data for the accident years 2000 to 2012 were considered. Furthermore only MAIS 2+ injured belt restrained (according to NASS CDS data set) drivers that had a frontal impact and where EDR data are available were included. This selection resulted in 188 cases.

For some of the cases the restraint system trigger time was not recorded in the EDR spread sheet. These cases were excluded from the analysis. The same is true for most of the analyses for the cases without airbag deployment. These 19 cases were analysed seperately. Following this selection 155 cases with available restraint system triggering time were included.

In a last step roll-over cases were excluded as well as cases without pictures of the case car. Finally 148 MAIS 2+ injured car drivers using the seat belt that were involved in a frontal impact accident in the years 2000 to 2012 without roll-over and available restraint system triggering time were included in the study.

Because the structural interaction appears to be an important influencing factor for the restraint system triggering, all cases were categorised as good structural interaction, under- / overrun, between rails or small overlap (impact zone outside the rails) respectively by checking the images of the deformed cars.

The delta-v of the case cars was retrieved from the EDR data in most of the cases except for cases where the delta-v was not available or wrong without doubts. The latter one was for example true for cases with interruption of the data storage process before the end of the impact phase. In some other cases the recorded delta-v does not fit with the vehicle deformation. For those cases the reconstructed delta-v was considered.

The restraint system triggering time is recorded in the EDR data set as the time between the algorhythm enable signal (normally a vehicle acceleration exceeding 2 g) and the driver airbag system triggering signal (in case of multiple stage airbags the trigger time of the first stage). In some cases the accident was recorded as two or more events in the EDR spread sheets. For those cases the time between preceeding non-deployment events were added to the triggering time of the deployment event.

For the GIDAS analysis frontal impact accidents of ECE R94 compliant cars (i.e., for this study year of first registration after 2003) with MAIS 2+ injured front seat occupants in cars with a front airbag at the relevant seating position were considered. The data set includes 91 occupants meeting the criteria. Structural interaction issues were identified using the CDC and the information in the database whether or not over- / underrun occurred. Delta-v information was obtained from the reconstruction.

DATA ANALYSIS

The data analysis is separated into the analysis of the NASS EDR data with airbag deployment, NASS EDR data without airbag deployment and the GIDAS data.

NASS EDR Data with Airbag Deployment

The focus of this study is the analysis of the restraint system trigger time and to evaluate the restraint system trigger time influencing factors. The distribution of the restraint system trigger time dependending on the delta-v is shown in Figure 3. The trigger time varies between 2 and more than 600 ms. The average trigger time is 65 ms. When comparing this time with the average trigger time in FWRB tests of approx. 7 ms [Dalmotas 2009], it is obvious that the trigger time in real world accidents is normally later. However, in an accident with a lower crash severity (e.g., expressed by the delta-v) than in the test it might be sensible to trigger the restraint system later in order to provide optimal performance.
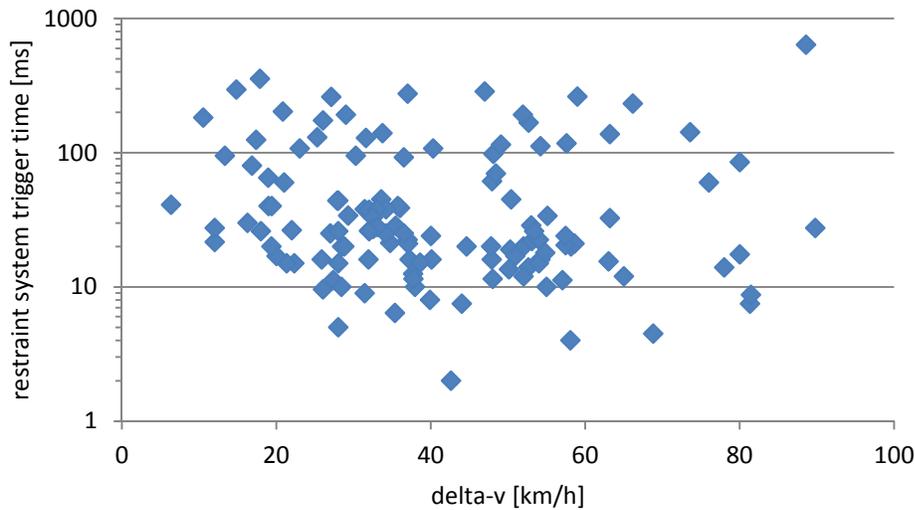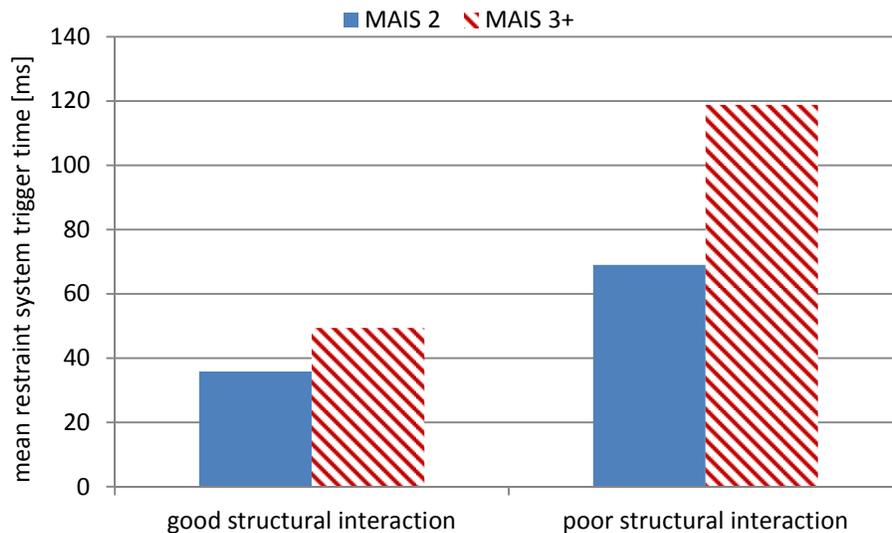
Figure 3. Restraint system trigger time dependent on delta-v for all 129 car drivers.

When dividing the accidents in groups with good structural interaction and those with poor structural interaction (i.e., small overlap, under- / overrun or between rails impact) the average trigger times are 48 ms in the good performing group and 89 ms in the group with poor structural interaction, respectively, see Figure 4.

accidents with good structural interaction

accidents with small overlap, impact between rails or under- / overrun
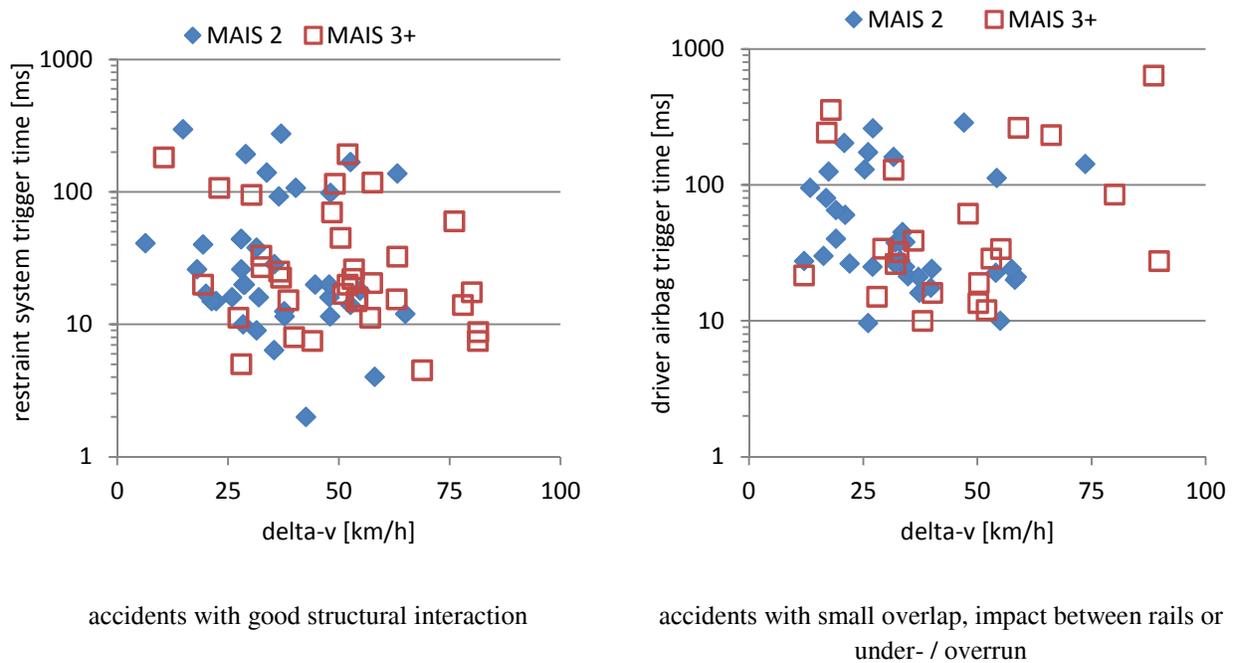
Figure 4. Injury severity depending on delta-v and restraint system trigger time for good and poor structural interaction.

Although even in the accidents with good structural interactions relatively late timing of the airbag was observed there are more cases with long trigger times in the group with poor structural performance, Figure 4. The mean trigger time for the MAIS 2 cases with good structural interaction differs only slightly from the MAIS 3+ cases, 36 ms compared with 49 ms, respectively – see Figure 5.

Figure 5. Injury severity depending on delta-v and restraint system trigger time for good and poor structural interaction.

For the cases with poor structural interaction the mean trigger time is much longer for both MAIS 2 and MAIS 3+ injured drivers compared to the cases with good structural interaction. Furthermore there is a large difference between MAIS 2 and MAIS 3+ cases in the group with poor structural interaction, 60 ms compared to 119 ms, respectively.

Further seperation of the group with poor structural interaction would lead to a too small sample size that would not allow further conclusions.

NASS EDR Data without Airbag Deployment

Looking at the cases without airbag deployment there are much more cases with poor structural interaction than with good structural interaction, see Figure 6. Furthermore 4 of the 5 non deployment cases with good structural interaction had a delta-v below 20 km/h, while this is true for only 3 of the 14 cases with poor structural interaction. In only one case with good structural interaction the non deployment resulted in MAIS 3 injuries while in 3 of the the cases with poor structural interaction the injury severity was MAIS 3, MAIS 4 and MAIS 5, respectively. The MAIS 3 case with good structural interaction was a multiple impact event – first with a small tree and approx. 30 m later with a wall – which could explain the MAIS 3 injuries.
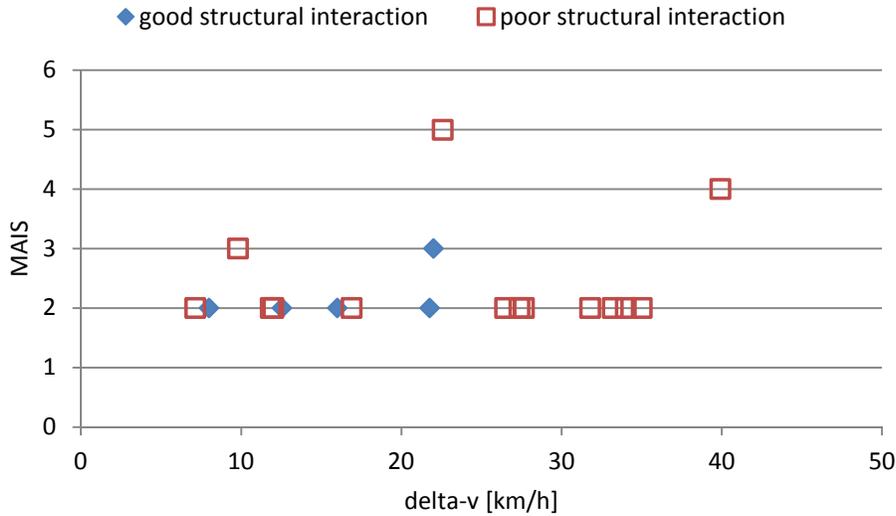
Figure 6. Delta-v and injury severity in non deployment cases.

GIDAS Data

The GIDAS data sample indicates that the injury severity for the head and chest is considerable higher in the cases with poor structural interaction. Especially for head, chest and abdomen it is expected that the injury risk is sensitive on the restraint system triggering time.For the arms and legs there appears to be no important difference between the accidents with and without good structural interaction. For the abdomen it is difficult to judge – the share of abdomen injuries is higher in the group with poor structural interaction while AIS 3+ injuries are only observed for the accidents with good structural interaction.
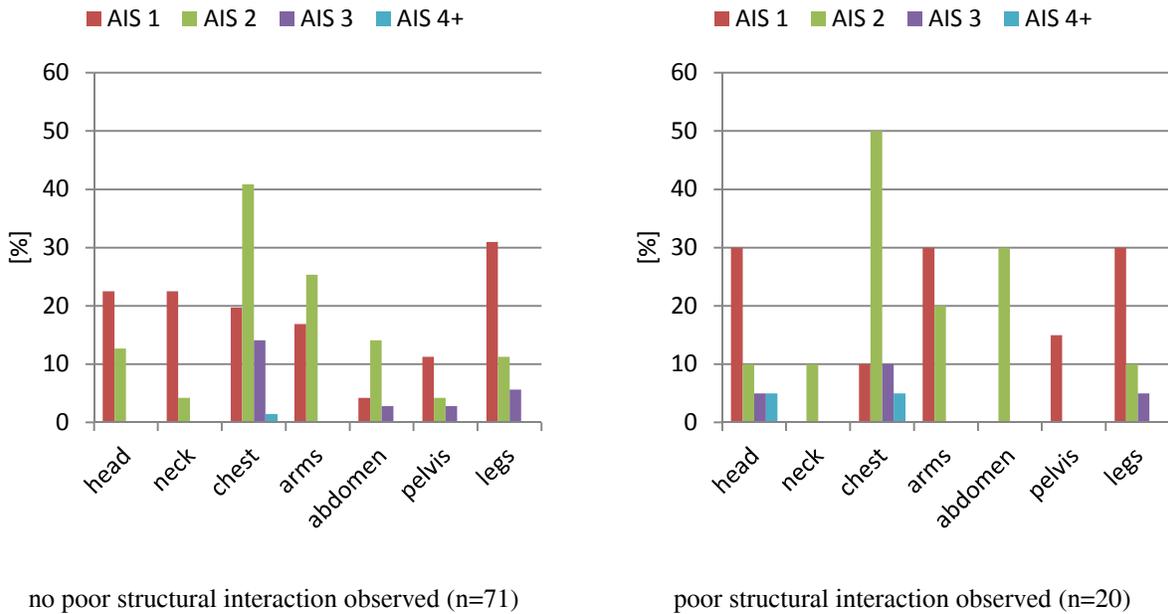

no poor structural interaction observed (n=71)   poor structural interaction observed (n=20)

Figure 7. Injury severity depending on structural interaction assessment.

DISCUSSION AND CONCLUSION

The analysed accident data indicates that restraint system triggering time is much later than in the standard tests (e.g., FMVSS 208 full frontal test) in a large number of cases. While triggering times just being later does not necessarily mean that they are too late. For example accidents with light accident severity require a late triggering of restraint systems. However, in a small number of crash tests it was proven that the late ECU airbag triggering results in considerably higher dummy readings.

The NASS EDR data with airbag deployment indicates that the restraint system trigger time tends to be later in cases with poor structural interaction (i.e., small overlap, impact between rails and under- / overrun scenarios). It is expected that the firing decision is more difficult to safeguard in these condictions compared for example with a FWRB test.

Furthermore the injury severity appears to be higher in cases with high accident severity and late restraint system trigger time. Furthermore the analysed GIDAS data shows that the injury severity for those body regions that are expected to be sensitive to the restraint system trigger time (i.e., head and thorax) is higher in the cases with poor structural interaction. This is interesting because those cases are expected to mainly increase intrusion related injury risks. However, for accidents with high accident severity and poor structural interaction it is also expected that the acceleration history would have a more injury causing shape (i.e., back loaded pulse).

Unfortunately for approx. half of the analysed NASS EDR data (accident years 2011 nd 2012) the individual injuries were not yet coded at the NASS CDS web site. Therefore it is not yet possible to confirm the observation from the GIDAS data sample with EDR data. The EDR data set mainly contains newer accident years due to the introduction phase of EDR.

As a next step it would be sensible to run accident reconstructions with observed and modifed restraint system trigger time in order to verify whether or not the timing was wrong in individual cases.

ACKNOWLEDGEMENTS

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