CRASH PULSE RECORDER - RESULTS FROM CAR ACCELERATION PULSES IN REAL LIFE FRONTAL IMPACTS

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ABSTRACT

Measurements of accident severity in real life accidents are often based on the crush energy of the studied vehicle. It is, however, important that the accident severity measurement not is possible to affect in the crash phase in an accident. In Sweden more than 60,000 cars have been equipped with a crash recorder aimed at measuring the crash pulse in real life frontal collisions.
This study shows results in terms of acceleration pulses and change of velocities measured with a crash recorder called Crash Pulse Recorder.
The car fleet has been followed over 3 years and in that time around 300 accidents have been collected. The accidents have been studied in detail, and apart from the crash recorder information, deformation measurements made with photogrammetric technique, interior inspection with video cameras and detailed medical information of the injuries have been analysed.
Especially accident severity distribution and injury risk versus accident severity is presented and discussed.

IN ANALYSES OF REAL LIFE ACCIDENTS, a few relationships showing different aspects of an accident sample are important for the analysis of a safety system. The number of accidents, the injury risk and the number of injuries at different accident severities are some of the basic relationships. It is also important to have an adequate accident severity measurement. It is essential that the accident severity parameter measured not is possible to affect during the crash phase in an accident (Kullgren, 1995). The best choice from that perspective would be the collision closing speed. It is however most of the times difficult to calculate it. Change of velocity is though, often possible to use and possible to calculate or estimate. Other accident severity measurements could be linked to acceleration levels as for example mean acceleration or peak acceleration. Acceleration measurements requires on board measurement technique.

Most of the times the change of velocity is calculated on the basis of the crush energy. These calculations has in several tests made for verifying the accuracy of such calculations, been shown to have too large errors, (Thomas, 1994, Smith, Noga, 1982, O' Neill, 1994, Kullgren, 1995). Table 1 shows systematic and random errors for different methods of calculating change of velocity. The last column shows results from crash recorders tested in full scale crash tests by Kullgren, 1995. The crash recorder showed the lowest standard deviation of 2.2 km/h. Systematic errors may be compensated for, but large random errors will always be a problem.

Table 1, Systematic and random errors in different methods of calculating change of velocity

	Smith/Noga	O'Neill	Thomas	Kullgren
Systematic error	± 15 %	- 9.0 km/h /15.4%	- 7.4 km/h /13.0%	- 3.9 km/h/8.9%
Standard deviation		4.2 km/h/7.1%	6.4 km/h/11.0%	2.2 km/h/5.5%
No of cases	53	26	29	51

In this paper an analysis of results from real life accidents with cars equipped with a low cost one dimensional crash recorder is presented. The crash recorder is an accelerometer and a recorder. It has been tested in several crash tests (Aldman et al, 1991, Kullgren, Lie, Tingvall, 1995). Table 1 shows results from the latest test.

In this study, distribution of ΔV and mean accelerationas as well as injury risk as a function of both ΔV and mean acceleration is presented. Also some accident cases are picked out and presented based on the link between injuries of different AIS code levels and change of velocity and mean acceleration of different ammount. These accidents have different accident modes with different shapes of the crash pulses and with different amount of intrusion involved. The injury outcome in relation to accident severity, in terms of both change of velocity and mean acceleration are discussed.

MATERIAL AND METHODS

The crash recorder, called Crash Pulse Recorder (CPR), has so far been mounted in 60.000 cars on the swedish market. The first CPR was installed in july 1992, and has since that been installed in 3 different car makes and in 10 car models. The car fleet has been followed for 3 years and every accident with a repair cost over a certain limit has been reported via a damage warranty insurance. In this time 300 accidents has occured, where the crash pulse has been recorded. Several of them were rollover accidents and some other type of accidents where the crash recorder information has a poor link to the injury outcome. These accidents are excluded in this study. This study includes results from 138 frontal impacts with a repair cost more than 7.000 USD. Apart from the crash recorder information, the injuries of the occupants has been collected and coded according to AIS85 and with body localisation and injury type. MAIS and accident severity for each accident has been compared in the analysis of the material. Also belt use has been concluded from interior inspections of the cars.

The CPR is based on a spring mass system where the movements of the mass in a collision is measured. It includes mechanical, electronical and optical features.The displacement of the mass is registered on a photographic film, where light emitting diods (LED), registers its location. The LED is driven by a crystall oscillator circuit which gives a modified square pulse with a frequency of 1000 Hz. The circuit has its own power cell and does not need an extemal power unit. The circuit is activated via a micro switch when the mass starts to move in a crash. The CPR has a trigger level of 2 to 5 g, chosen so as to avoid recording of manoeuvre deceleration.

After an impact the recordings on the photographic film are scanned into a computer. The computer finds the grey level center of gravity for each mark. From these measurements the displacement of the mass can be obtained as a function of time. With all characteristic parameters for the CPR measured and with knowledge of the displacement time history, the acceleration time history can be calculated. The crash pulses are filtered with approximately 100 Hz.
Change of velocity and mean accelerations have then been calculated from the crash pulses.

RESULTS

In Fig 1 the number of accidents at different change of velocities are presented and in Fig 2 the number of accidents at different mean accelerations are presented. In Fig 1, 95 % of the accidents has a change of velocity below 39.0 km/h.

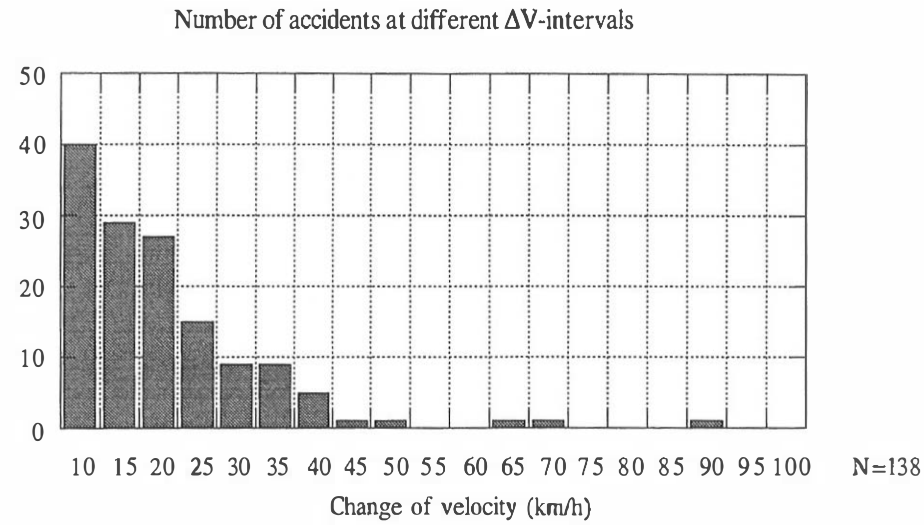

Fig 1, Number of accidents at different change of velocity intervals

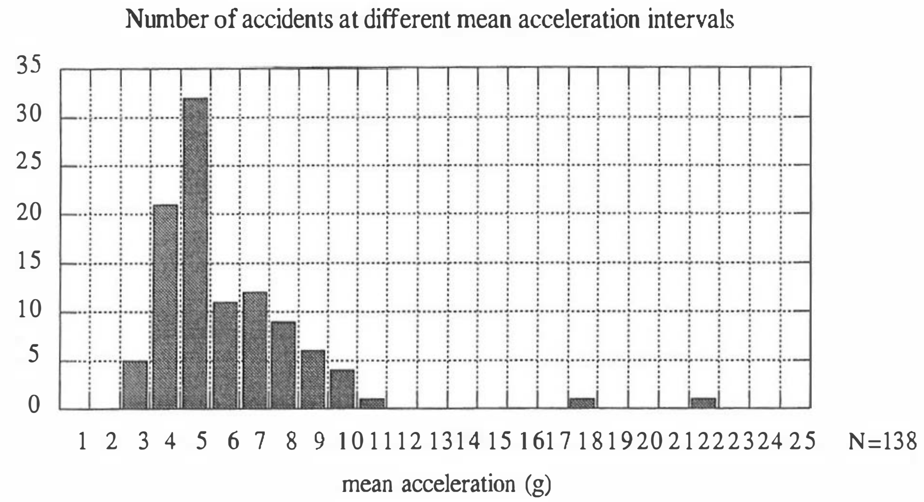

Fig 2, Number of accidents at different mean acceleration intervals

Fig 3 presents the injury risk at different change of velocities and Fig 4 shows injury risk at different mean accelerations.

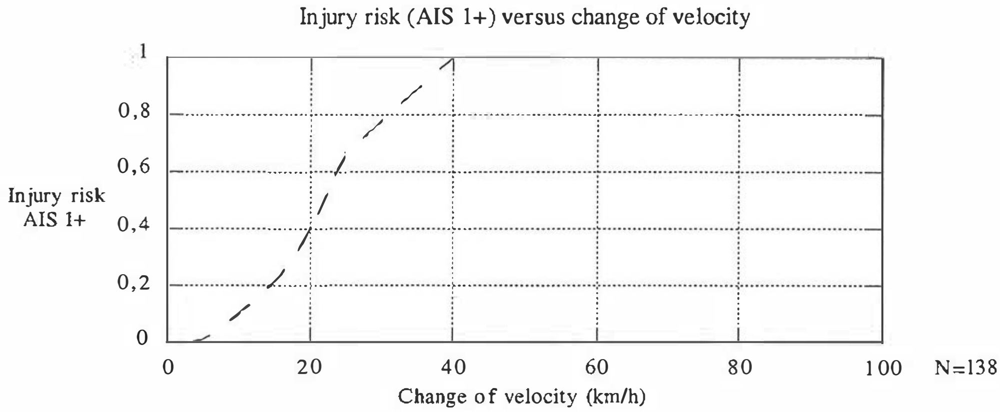

Fig 3, Injury risk versus change of velocity

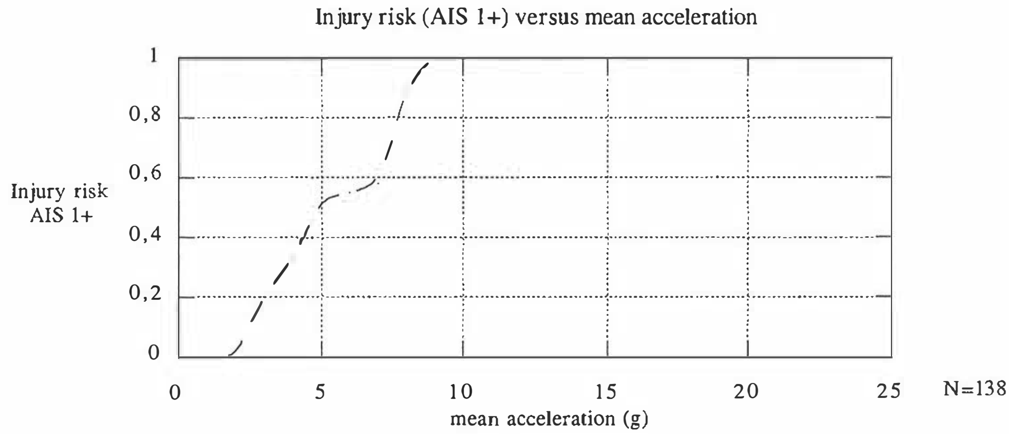

Fig 4, Injury risk versus mean acceleration

Some of the information from the curves in Fig 3 and Fig 4 are discribed in Table 2, where it can be seen when different MAIS levels of injury occured concerning lowest and highest change of velocity and mean acceleration. The figure in parenthesis shows the accident number presented in Table 3.

Table 2, MAIS injuries at lowest and highest ΔV and mean acceleration

	no injury	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	MAIS6
Lowest ΔV	-	7.1 (3)	17.8 (6)	27.1 (9)	-	39.1 (11)	-
Highest ΔV	31.2 (1)	66.8 (4)	89.1 (7)	64.8 (10)	-	-	-
Lowest mean acc	-	3.0 (3)	4.3 (8)	6.2 (9)	-	9.8 (11)	-
Highest mean acc	7.1 (2)	9.7 (5)	21.0 (7)	17.2 (10)	-	-	-

Table 3 describes the accidents behind the figures in Table 2. The accident type and injury outcome (MAIS) are included. Fig 6 to 16 shows the crash pulses and ΔV time histories from the accidents presented in Table 3.

Table 3, 11 accidents

Accident no	accident type	ΔV	mean acc	MAIS
1	Single accident, road rail, 100% overlap	31.2	5.3	-
2	Car to car, 40 % overlap	24.8	7.1	-
3	Car to car, into side of struck vehicle	7.1	3.0	1
4	Single accident into a rock, 85 % overlap	66.8	8.2	1
5	Single accident into a tree	34.9	9.7	1
6	Car to car, 100 % overlap	17.8	4.9	2
7	Car to car, 70 % overlap	89.1	21.0	2
8	Car to car, sideswipe	18.3	4.3	2
9	Car to car, 25 % overlap	27.1	6.2	3
10	Car to car, into side of struck vehicle	64.8	17.2	3
11	Car to car, 30 % overlap	39.1	9.8	5

The pulse with the highest change of velocity was 89.1 km/h, and the highest mean acceleration was 21.0 g. The pulse with longest time duration was 230 ms. The highest peak acceleration was 90 g.

Fig 5 shows mean acceleration and change of velocity for all included accidents, where the accidents have been divided in uninjured, MAIS1- and MAIS2+-injuries. The figure also shows the relation between mean acceleration and ΔV.

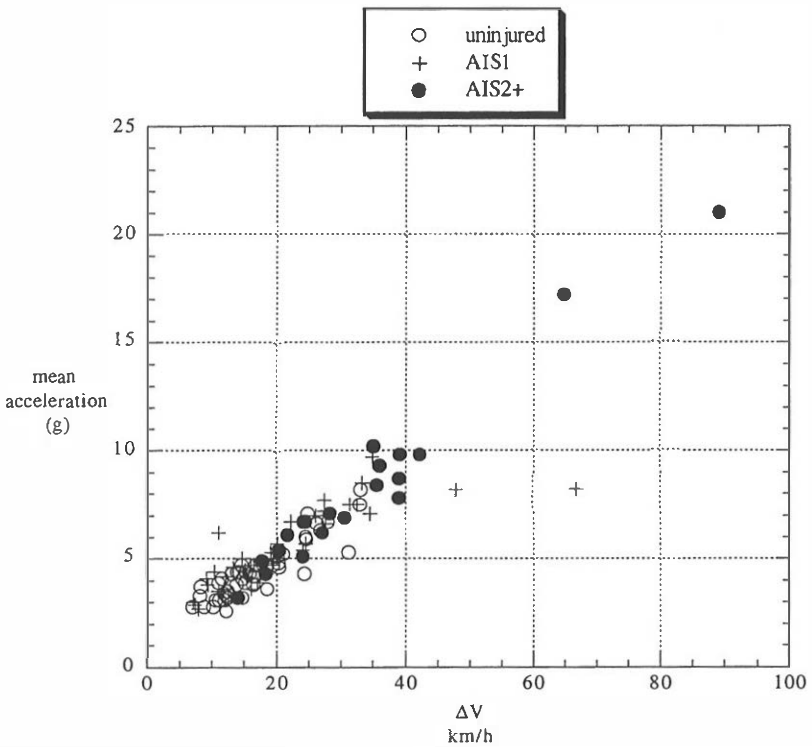

Fig 5, Mean acceleration and ΔV for all accidents

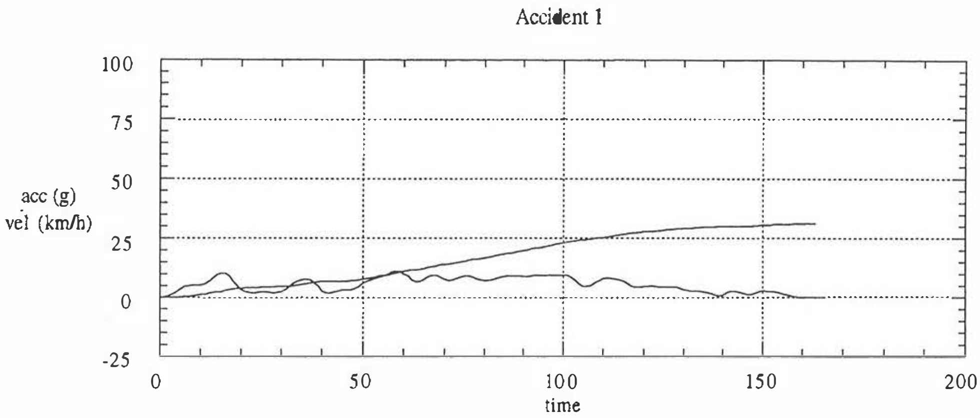

Fig 6, Accident 1: !00 % overlap, ΔV 31 km/h, no injuries

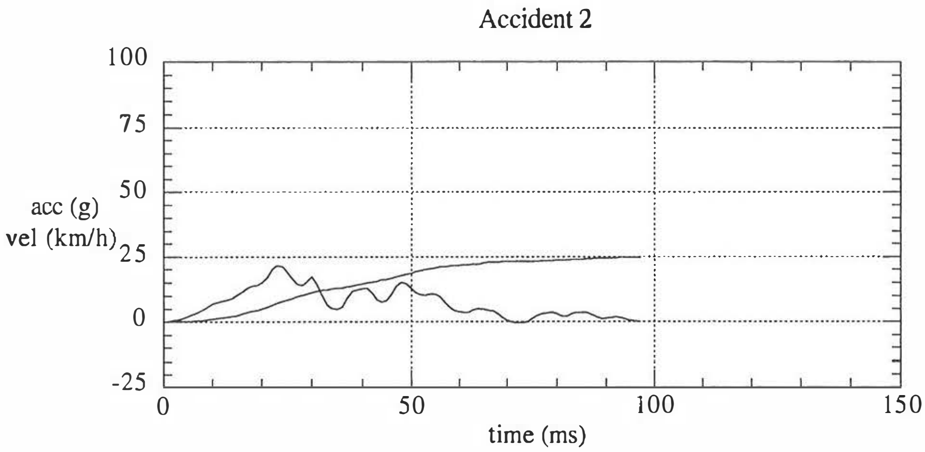

Fig 7, Accident 2: 40 % overlap, ΔV 25 km/h, no injuries.

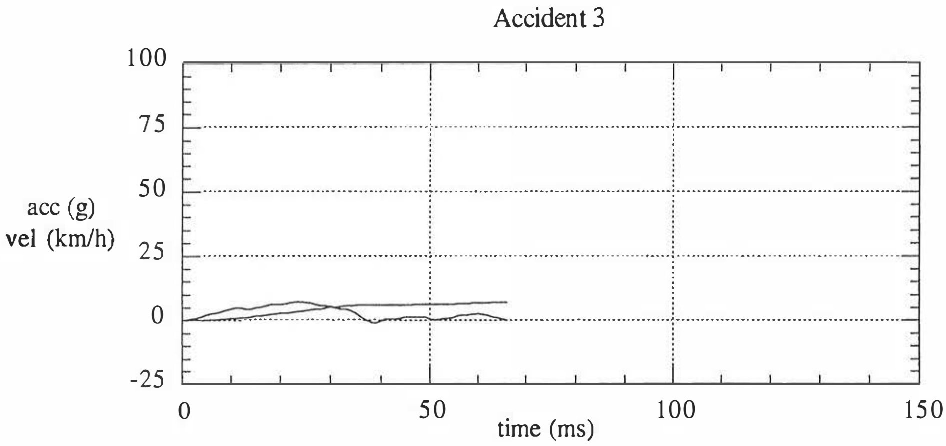

Fig 8, Accident 3: 100 % overlap, ΔV 7 km/h, MAIS 1.

Accident4

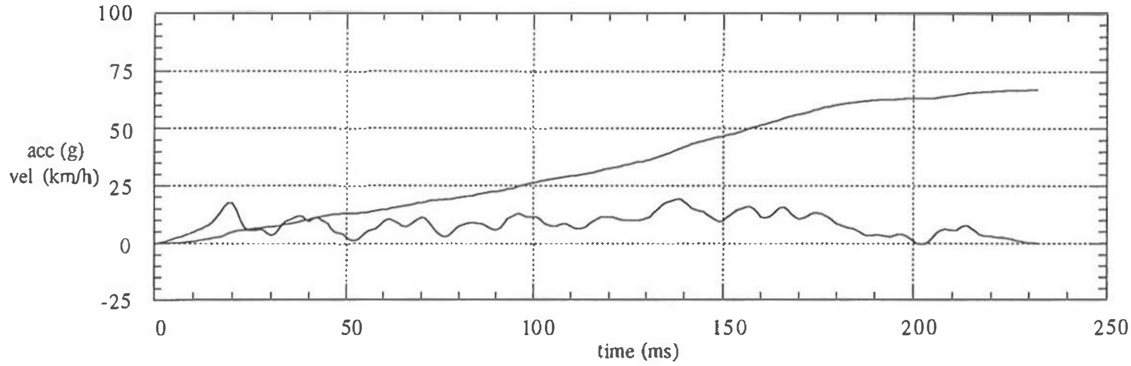

Fig 9, Accident 4: 85 % overlap, ΔV 67 km/h, MAIS 1.

Accident 5

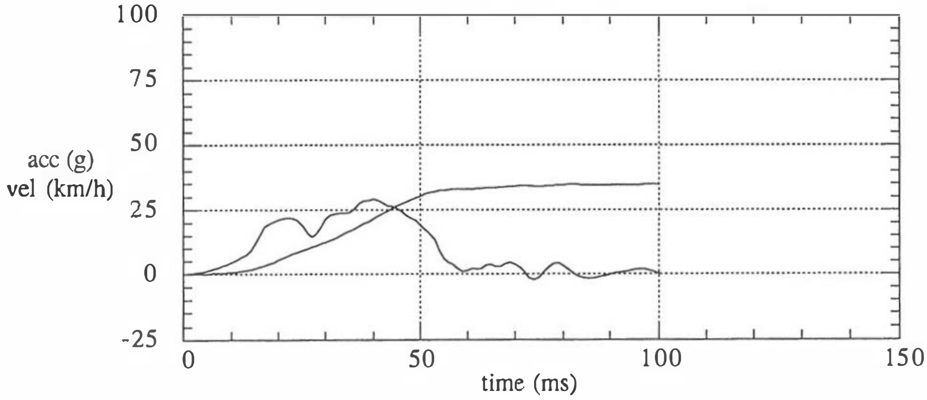

Fig 10, Accident 5: tree, ΔV 35 km/h, MAIS 1.

Accident 6

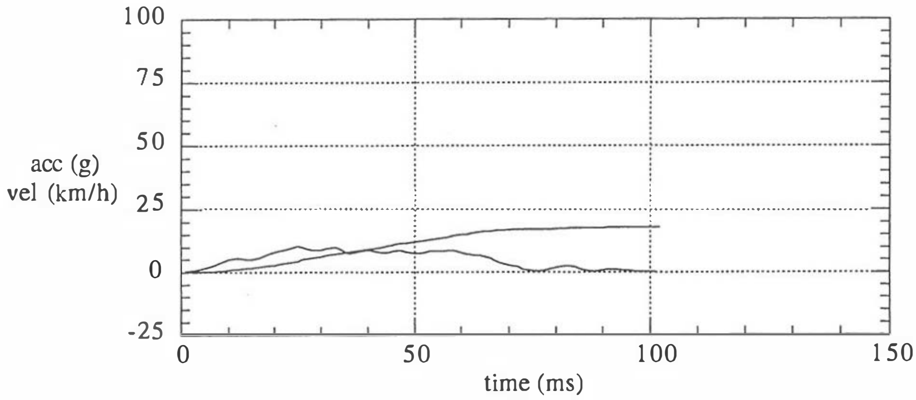

Fig 11, Accident 6: 100 % overlap, ΔV 18 km/h, MAIS 2.

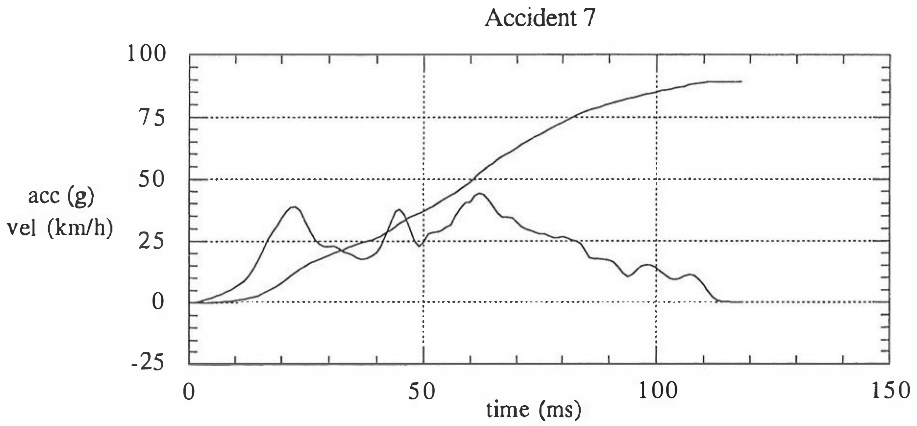

Fig 12, Accident 7: 70 % overlap, ΔV 89 km/h, MAIS 2.

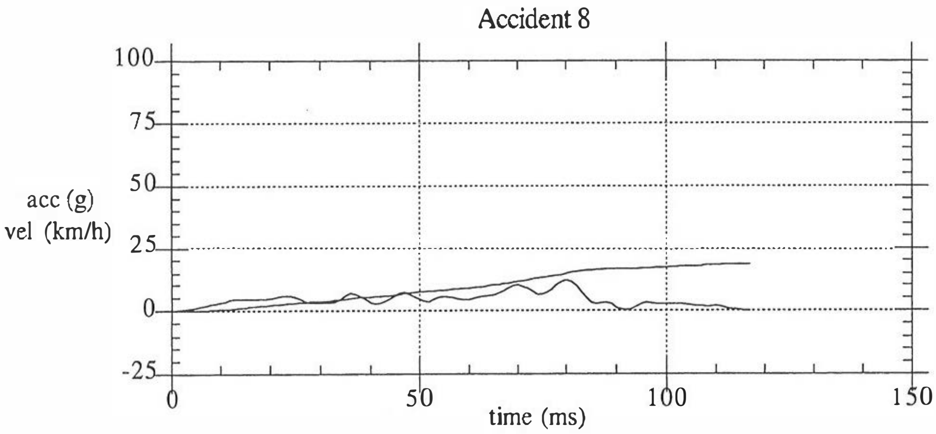

Fig 13, Accident 8: sideswipe, ΔV 18 km/h, MAIS 2.

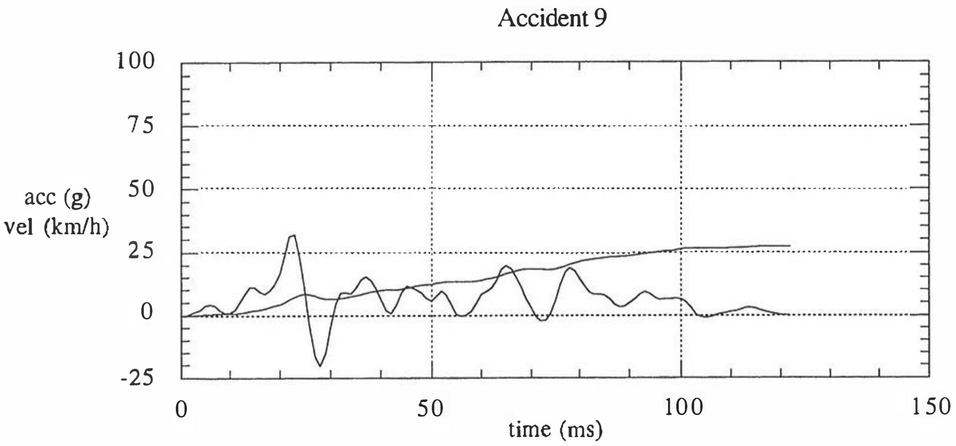

Fig 14, Accident 9: 25 % overlap, ΔV 27 km/h, MAIS 3.

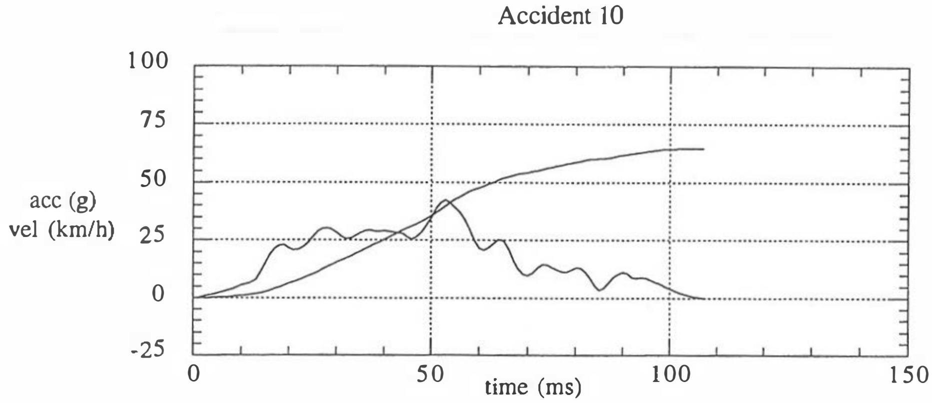

Fig 15, Accident 10: 100 % overlap, ΔV 65 km/h, MAIS 3.

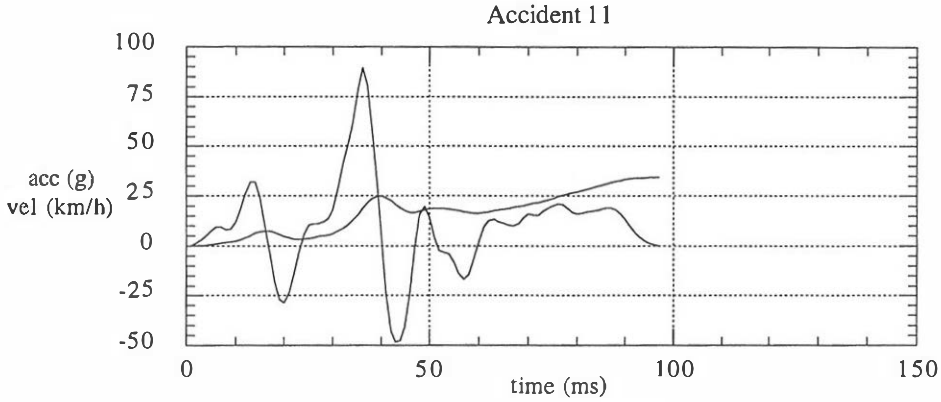

Fig 16, Accident 11: 30 % overlap, ΔV 39 km/h, MAIS 5.

DISCUSSION

In analyses of real life accidents it is essential to verify the number of accidents, the injury risk and the number of injuries at different accident severities. It is important that the accident severity measurement is independent of the behaviour of the vehicle in the crash phase in an accident (Kullgren, 1995). The collision closing speed between two vehicles or between a fixed obstacle and the colliding vehicle would fullfil that requirement. It is, however, most of the times impossible to measure or estimate. One parameter which to a small amount may be affected by the cars behaviour in the crash phase is the change of velocity. It is often possible to use and possible to measure or calculate. Most of the times the change of velocity is calculated from the Equivalent Barrier Speed, EBS, which in turn is calculated on the basis of the crush energy. These calculations has in several tests made for verifying the accuracy of such calculations, been shown to have too large errors, (Thomas, 1994, Smith, Noga, 1982, O' Neill, 1994, Kullgren, 1995), see Table 1. EBS is a commonly used accident severity parameter since it is relatively easy to calculate and since it gives a direct correlation to laboratory conditions. The EBS is though linked to the stiffnesses of the involved vehicles and is therefore not an independent accident severity parameter.

In this study a crash recorder aimed at measuring the crash pulse in accidents is used in a large field study. On the swedish market more than 60,000 cars have been equipped with a crash recorder aimed at measuring the crash pulse in real life frontal collisions. The car fleet has been followed over 3 years and all accidents have been reported via a damage warranty insurance.

The inclusion criterion for the accidents in this study has been both a matter of crash mode and a repair cost. Only frontal impacts are included since the CPR is measuring frontal impacts in a range of ±30 degrees. The limit of the repair cost is set to be above 7,000 USD. In total 300 accidents have been collected, but only a part of these accidents have been used in this study. Excluded are rollover accidents and accidents with multiple impacts where it is hard to link the injury outcome to one of the selected accident severity measurements. Also angled collisions with an angle exceeding ± 30 degrees are excluded.

The crash recorder has been tested in several full scale crash tests (Kullgren, 1995). In that study the crash recorder showed a low standard deviation of 2.2 km/h, see Table 1. It is important have a small random error, systematic errors may be compensated for but large random errors will always be a problem.

In a study by Norin, 1994, the number of accidents is presented versus EBS-intervals instead of ΔV, see Fig 17. Included in that study are all frontal accidents with belted drivers and with a repair cost more than 3.500 USD. In that study 95 % of the accidents had an EBS below 42 km/h.

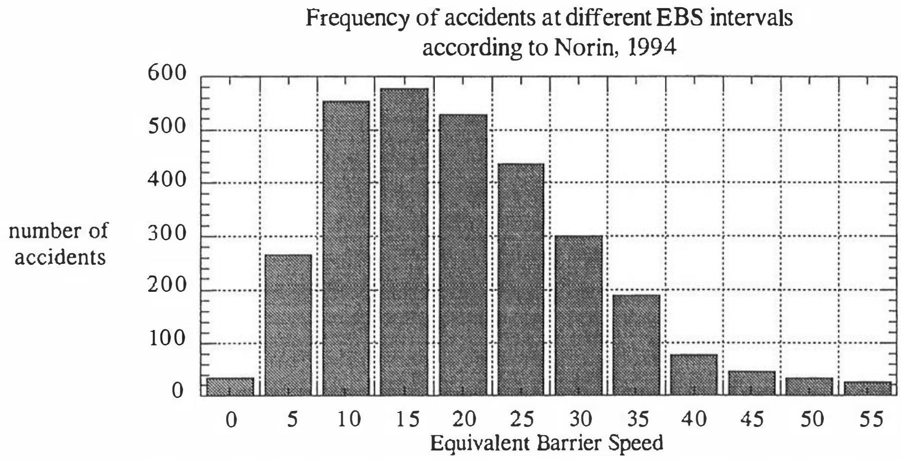

Fig 17. Number of accidents at different EBS intervals, Norin, 1994.

In the frequency of ΔV in this study, showed in Fig 1, 95 % of the accidents has a change of velocity below 39 km/h. There are difficulties in comparing the results since the accident severity measurements are different in the studies. EBS may in some accidents be very different from ΔV.

The shape of the curve in Fig. 17 and Fig 1 is a result of two curves, the actual number of accidents and the amount of reported accidents at different accident severities, which in turn depends on the inclusion criterion as for example the repaircost.

In Fig 2 a peak can be seen at the acceleration level of 5 g. Although there is some link between ΔV and mean acceleration, as shown in Fig 5, the shape of the curves in Fig 1 and Fig 2 will be different.

In the presentations of injury risk, all AIS 1 injuries and more severe are included. The first AIS 1 injury occured at a change of velocity below 10 km/h. At a change of velocity of 40 km/h the injury risk is 100 %. Concerning mean acceleration the corresponding figure is 9 g.
A curve representing risk of fatal outcome versus change of velocity are presented by Evans, 1994. In this curve the risk of fatal outcome starts at 40 km/h and is 100% at 106

km/h, see Fig 18. The shape of the risk of fatality is in Evans study described as; risk=$(\Delta V/106)^{4.51}$.
Comparing Evans risk of fatality with the results in Fig 1, it seems like the shape of the risk curve will change according to the severity of the injured under study. The more severe injuries studied the lower slope the risk curve will have.

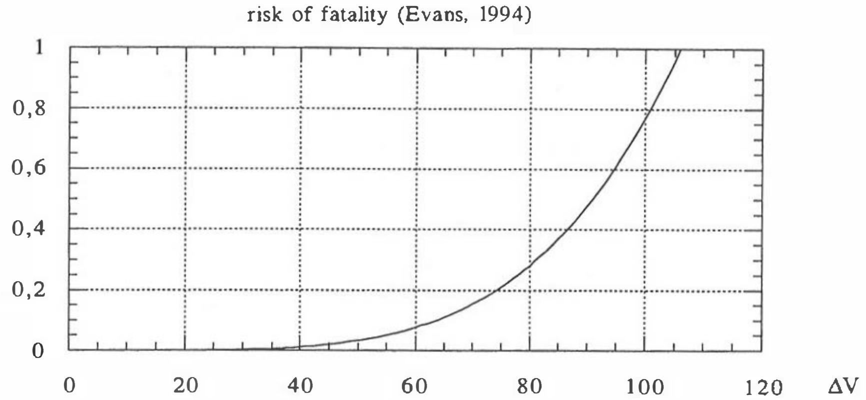

Fig 18, Fatality risk versus ΔV, Evans 1994.

The curve for the injury risk versus mean acceleration in Fig 4, shows that there is a strong correlation between injury risk and mean acceleration, although it probably will be better correlations to the injury outcome with other acceleration based measurements as for example the peak acceleration.

In this sample of accidents, many of the MAIS1 injuries in the low speed segment are caused in either sideswipe or narrow offset collisions or caused by a driver side airbag. An example of this can be seen in Table 2, where the first AIS 2 injury occured at 17.8 km/h. The injury in that case was a broken arm caused by the driver side airbag. A few cases where the driver was unbelted may also be involved.

The correlation between mean acceleration in ΔV can be studied in Fig 5. The accidents with injured drivers in the segment with low ΔV and low mean acceleration are often narrow offset or sideswipe collisions. In some cases the injury was caused by an airbag.
Excluding the accidents where the injuries are caused by other parameters than acceleration levels would make it possible to see a a limit concerning both mean acceleration and ΔV, above which there is a segment with all accidents with injuries.

The shape of the crash pulses in this study showes a substantial variation. Concerning duration of the pulse it varies from 40 ms up to 230 ms. Especially in the sideswipe and narrow offset collisions the shape may be very complex, see Fig 15.

When comparing accident severity in terms of acceleration measurements with the injury outcome, it is important to exclude accidents where the intrusion is a better severity measurement or for example accidents where an airbag has caused the injury. In further analyses of the material when more accidents with crash recorders has occured, more detailed analyses will be possible to obtain. The risk of having an AIS 1, AIS 2, AIS3 etc -injury, may be possible to calculate. It will also be possible to differentiate the injury risk to different body regions. Also other accident severity parameters as peak acceleraion and other pulse shape dependent parameters may be possible to link to the injury outcome.

CONCLUSIONS

From the accidents included in this study the following conclusions can be made:

- 95 % of all accidents, with the inclusion criterion in this study, are below 39 km/h.

- In the accidents in this study, there is a strong correlation between injury risk and both ΔV and mean acceleration.

- Most of the severe injuries were caused in narrow offset collisions with large intrusion.

- It is important to distinguish between accidents where the injuries are caused by intrusion and those where they are caused by high acceleration levels or high change of velocities.

- It seems desirable to have a more advanced measurement of the accident severity, taking both change of velocity and some acceleration measurement into account. The CPR gives a possibility to develop such a measurement.

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