IN-DEPTH STUDY OF VOLVO CARS IN ROLLOVER ACCIDENTS

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ABSTRACT

Rollover is not the most common type of accident, but the consequences may be serious. Understanding of the injury mechanisms during the complex rollover movement is limited and requires further investigation.

In-depth investigations of 21 Volvo cars involved in rollover crashes were analysed with regards to cause and outcome. Detailed information was examined about the crash scenario, the roadside environment, the car, its occupants and injuries, if any occurred. Parameters such as the initiation of rollover, the rollover kinematics, the deformation of the car and the environmental interaction with the car were analysed with a view to determine a measure of rollover severity.

As a complement, the results from the in-depth investigations were compared with statistical analyses of rollover cases in Volvo's accident database and the NASS database. The results from these databases support the findings from the in-depth study.

Having this comprehensive knowledge about the crash performance and kinematics, no single parameter or combination of parameters was found appropriate for describing the rollover severity related to injury risk. On the other hand, conclusions are drawn regarding deformation characteristics, the initiation of rollovers, the number of turns, the roll direction, where the rollover takes place, the body parts most often injured, and the most common injury mechanisms.

ROLLOVER CRASHES ARE VERY COMPLEX in terms of vehicle motion, occupant kinematics, occupant contacts within the vehicle's interior and possible occupant contact with the road or ground surface. Keeping this complexity in mind, it is understandable that finding a way to determine rollover crash severity is not easy. For instance Terhune et al, 1991, did not manage to define good measures of rollover crash severity, while studies by Digges and Klisch, 1991, indicate vehicle speed as an important parameter.

Of the injury mechanisms discussed in the literature the mechanism of head and neck injuries is the most frequently mentioned. Neck injuries can be caused by the occupant hitting the roof: either by the occupant moving towards the roof, resulting in a diving-type injury or by the roof itself being crushed (Bahling 1990, Orlowski 1985). The extent of roof crush could be an indicator of the injury severity, but according to Rechnizer et al, 1998, Mackay, 1991, Piziali et al, 1998, roof crush is not a factor in determining injury severity.

Another mechanism of injury is complete or partial ejection during the rollover. Rechnitzer et al, 1996, report partial ejection of the head occurring, even if the occupant was belted, resulting in severe head-crushing injuries.

There are only two standard test procedures for rollovers; one dynamic and one static. The dynamic test method is the US legal requirement FMVSS 208; describing a test which initiates a rollover around the longitudinal axis of the car. The FMVSS 208 test method is mainly for testing partial ejection. The test method is widely used and is quite simplified for being a rollover, and there may be a great variability in number of turns, roof deformation and final position. Only the first roll could be made reproducible, according to Rechnizer et al, 1998.

The static test is for roof crush resistance, the FMVSS 216. The roof is deformed by a plate until a certain force is reached. This force has to be reached within 127 mm.

Apart from these two rollover test methods several types of non standard rollover tests are used. For example, rollovers initiated by soil, a ditch or a ramp (Cooperrider et al, 1998, Wech and Ostmann 1996, Winn 1989, Brown 1985).

One objective of this study was to define rollover crash severity measures by identifying and correlating the occupant injury mechanisms with the analyses of accident material. Another aim was to categorise the car damage and find the relevance of existing rollover test methods.

METHODS

This study is mainly based on in-depth analyses of rollover cases involving Volvo cars. In support of the results from the in-depth study two statistical analyses of specific parameters were performed: one in the Volvo statistical accident database and one in the NASS database.

IN-DEPTH STUDY

A total of 21 Volvo cars involved in rollover accidents were analysed with regard to cause and outcome. The car model years ranging from 1985-1995 and accident years 1986-1996. The crashes are all registered in the files of the Volvo accident database of in-depth studies. Volvo's accident commission has regularly investigated accidents of particular interest since the start in 1970. The in-depth database contains of approximately 2,500 cases, containing detailed information about the crash scenario, the roadside environment, the car and the occupants, and injuries, if any.

The selection criteria for this specific study of rollover accidents were a) rollover or multiple accident including rollover, b) belted occupants, and

c) Volvo 700/900 or Volvo 800 models. A rollover is here defined as more than 90 degrees in the x or y direction.

Based on these criteria, a total of 21 cars were included in this subset. The distribution of occupant characteristics and injury outcome is summarised in table 1.

Table 1. Data of in-depth study

	#
No. of accidents	21
No. of belted occupants	39
No. of injured occupants (belted)	26
MAIS 1	19
MAIS 2+	7
Total no. of injuries	55

Available information for each case included: in-depth report by accident investigator, police report of the accident, questionnaire answered by the owner of the car, medical records, and photos of the car. For each case, a total of 35 parameters were described concerning the occupants, possible injury mechanisms, rollover configuration, roadside environment, car deformation as well as observations on the exterior and interior.

Car deformation was categorised in different groups. Deformation modes were chosen based on the visual appearance of the car deformation and were used primarily in comparing to different laboratory test results. The ambition was to see if the types of deformation found in real life accidents could be similarly produced in laboratory tests. The laboratory test methods chosen were FMVSS 208, SAE J857, screw-rollover test, and FMVSS 216. The FMVSS 216 was extended with more angles.

The cases were categorised into different types of rollover situations. When identifying a specific case, all available information was used, such as the roadside environment, rollover configuration and car deformation.

In the efforts to identify rollover severity measures a correlation matrix was developed. A rollover severity measure is defined as a severity variable with good correlation to the injury to the occupants. The occupant injury variables were MAIS of head, neck, chest, spine and upper extremities. As severity variables, variables prior to impact or during impact should preferably be chosen. Four main specific variables were chosen and studied: velocity of car prior to rollover, number of turns in x-direction, initiation of rollover, and rollover surface. The correlation of car deformation and occupant injury was also studied even though car deformation is not a severity measure according to the definition.

Combined severity variables were used, as a second step in the effort to define a rollover severity measure. Examples of combinations were: "initiation of the rollover*rollover surface*deformation of the car", "initiation of the rollover*rollover surface*velocity of the car before starting roll divided by ten*number of turns", "initiation of the rollover*rollover surface*velocity of the car before starting roll divided by ten", "velocity of the car before starting roll divided by ten" and "initiation of the rollover*rollover surface".

VOLVO'S STATISTICAL ACCIDENT DATABASE (STO)

Apart from the in-depth database, Volvo has a statistical accident database STO. The statistical accident database contains information on crashes with Volvo cars in Sweden during accident years 1976-1998. The accidents registered are those involving Volvo cars with Volvia Insurance, and with a repair cost exceeding a certain amount (currently SEK 35,000), irrespective of whether there was an occupant injury or not. The total database contains data on approximately 28,000 Volvo cars and more than 48,000 occupants (60% of the cases are non-injury cases).

For this rollover study the following cases were selected for analysis: a) pure rollover accidents without collision, b) belted occupants older than 12 years, c) occupant weight more than 36 kg and height more than 140 cm, d) Volvo cars from the 700, 900 and 800 models.

Details regarding the subset are found in table 2. Some of the cases could be identical to the cases in the in-depth study, but are not necessarily so because of the different selection criteria.

Table 2. Data of the STO subset

	#
No. of accidents	595
Belted occupants	914
No. of injured occupants (belted)	448
MAIS 1	365
MAIS 2+	83
Total number of injuries	850

The variables mainly studied were the deformation depth of the roof and injuries to the occupants.

NASS (NATIONAL ACCIDENT SAMPLING SYSTEM)

In the NASS database, interesting variables can be found describing the initiation and the event course of rollovers. With the ambition of comparing with Volvo in-depth cases, only cars in approximately the same size and weight class as Volvo cars were chosen. The data was not weighted. Only belted occupants were studied. The portion of pure rollovers in the NASS subset is approximately 5%.

The subset consists of the following data: a) rollover accident without collision, b) cars between 1300-1600 kg, c) body type 4 door sedan/hardtop, station wagon, 5door/4door/3door/2door hatchback. The NASS sampling years were 1993-1995.

The restrictions above gave a selected sample of 166 cars with 288 occupants, as specified in table 3.

Table 3. Data of the NASS subset

	#
No. of accidents	166
Belted occupants	145
No. of injured occupants (belted)	125
MAIS 1	67
MAIS 2+	57
Total number of injuries	510

Variables examined in this study were; location of rollover, rollover initiation object contacted, rollover, rollover-initiating type, direction of initial rollover, injuries to the occupants.

RESULTS

IN-DEPTH STUDY

Injuries and injury mechanism Among the belted occupants the body parts found to be most frequently injured (AIS1+) were head, arms, face and legs. The distribution of injuries with respect to body region and level of AIS is shown in table 4.

Table 4. Distribution of injuries for belted occupant with respect to body region and AIS level with the exception of two AIS 1 injuries to unknown body part.

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6
Head	14	3				2
Face	7		2			
Neck	4		1			
Spine	1		2			
Chest	2	1				
Pelvis						
Arms	4	4				
Legs	6					

The severe to fatal injuries were found in the spine, head, face and neck. For each in-depth case, an attempt was made to assess possible contact surface and possible injury-producing mechanism. Four groups of injury-producing mechanisms were identified: a) minor impact (e.g. arm impacting door), b) impact with body load (e.g. diving type of mechanism), c) impact together with friction (e.g. contacting the ground), c) non-impact type of mechanism (e.g. whiplash). The number of injury cases in each injury mechanism group together with examples of types of injuries is shown in table 5.

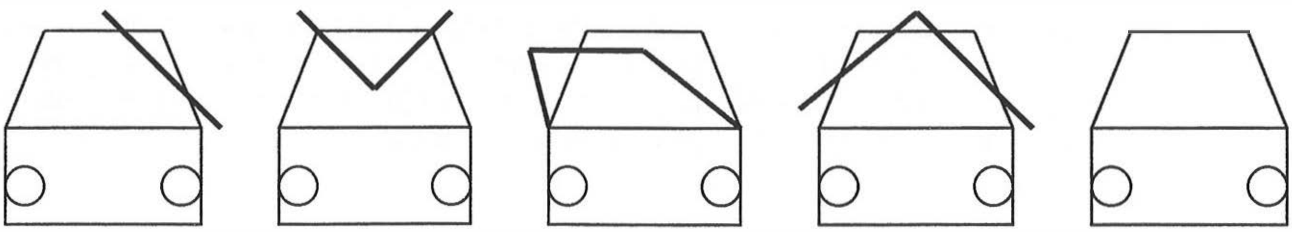
Table 5: Examples of injury types with respect to injury-producing mechanisms.

Injury mechanism group	Amount of injuries	Types of injuries
a) minor impact (minor body load)	32	mainly AIS 1 injuries except 2 AIS 2 arm injuries and 1 AIS 2 head injuries
b) impact with body load	11	4 AIS 1 injuries and 2 AIS 2 head injuries 2 AIS 2 arm injuries 2 AIS 3 spine injuries 1 AIS 3 neck injury
c) friction impact	2	fatal injuries: 2 AIS 6 head injuries 2 AIS 3 face injuries
d) non-impact	8	4 AIS 1 neck injuries 2 AIS 1 and 1 AIS 2 chest inj. 1 AIS 1 face injury

The most common group of mechanisms is minor impact, e.g. arm and head impacting different surfaces with minor body load. However, this injury-producing mechanism group accounts mainly for the minor injuries. The outcome becomes more severe if the impact is combined with body load, such as the head impacting the roof with the body weight applied during the impact. In this sample of in-depth cases, the most severe injuries occurred when parts of the occupant impacted the ground. Due to the rough surface of the impact, fatal head injuries with corresponding severe face injuries were caused.

Details of the injuries, contact surfaces and injury-producing mechanisms for each of the 21 cases are found in appendix 1.

Deformation modes and test method comparison Five deformation modes were chosen to characterise the car deformation . The principle for each mode is shown in Figure 1. Group O consists of two cars with undeformed roofs and pillars. Case U is not grouped into any mode since exterior photos were missing. Some of the cases are categorised in two modes. The mode for each specific case can be found in appendix 1.



T (9 cases) M (5 cases) S (6 cases) R (2 cases) O (2 cases)

Figure 1. Deformation modes

In this sub set, the most common deformation mode is “T”, followed by “S” and “M”.

When compared to laboratory test methods (as identified in the previous chapter; Methods), 11 of the 21 in-depth cases could be described by a test method. The cases which had no similarity in deformation characteristics with a test method were the cases identified as deformation modes “M” and “R”. Also some cases of “S” mode did not fit into a test method.

Rollover situation versus occupant injury Categorising rollover situations resulted in seven different groups, as described in table 6.

Table 6. Rollover situation by group.

High roll	Rollover higher than one meter above the ground.
Low roll	Rollover close to the ground, below 1 m.
Side gliding	Car sliding on its side in the longitudinal direction (during the rollover sequence).
High fall	Car falling down a slope, landing on the roof
Local object	Uneven surface with large local object causing car deformation
No roof deformation	No deformation of roof
Unknown	No exterior deformation data available

When summarising the rollover situations (as in table 6) and combining them with occupant injuries, the following results were found; table 7. Only the most severe occupant injury in each car was considered.

Table 7. Combination of occupant injury and rollover situation. Letters refer to the 21 cases studied, see appendix 1.

Situation	No injury	Injured AIS1	Injured AIS2-6	#
High roll		A G P	D H R X	7
Low roll	B I	E J K O N V M	L	10
Side gliding			D	1
High fall			F	1
Local object		J K M N	L	5
No roof deformation		S T		2
Unknown	U			1

Most AIS2+ injuries were caused during a “high roll”. It should be noted that the cars in the "local object" situation are also in the "low roll" situation. The conclusions drawn from these findings are that a high-energy rollover, usually with a complex rollover pattern, results in more severe injury outcome. Hence, it is not the degree of deformation depth of the car, as a single variable, that induces injuries.

Rollover severity measures For the variables describing rollover configuration, the results show that more than 85% of the cars analysed have an initial velocity of 100 km/h or less. In more than 60% of the cases the number of turns is less than or equal to one turn. The initiation of the rollover is usually initial ramp-up, lateral acceleration, or collision. The roadside is the most common rollover surface, valid for 50% of the cases. Ditches account for almost 40% of the cases.

When studying overall car deformation, 90% of the cars had 25 cm or less deformation depth.

No good correlation was found between the variables prior to the rollover and injuries to the occupants, see appendix 2.

A correlation factor of 0.47 (see appendix 2) was found between the deformation of the car (at the position of the occupant) and injuries to head. This was due to the two fatalities who both sustained their injuries under similar conditions and mechanisms, partial ejection of the head, as grouped c) (friction impact, see table 5). The car deformation did not a play part in the outcome of these two cases. When excluding these two cases the correlation factor was 0.29, and no relation was found between the degree of local car deformation and injury severity.

RESULTS FROM STO

90% of the cars had the maximum roof deformation equal to or less than 20 cm.

51% of the occupants were uninjured, 40% sustained MAIS1 injuries, 4.7% MAIS2 injuries and 4.3% MAIS3+ injuries. Body parts most frequently injured were head, neck and arm (also the highest injury risk of AIS1 injuries). Regarding AIS2 injuries the head and arm accounted for the highest injury risk, whilst for AIS3+ head and spine dominated.

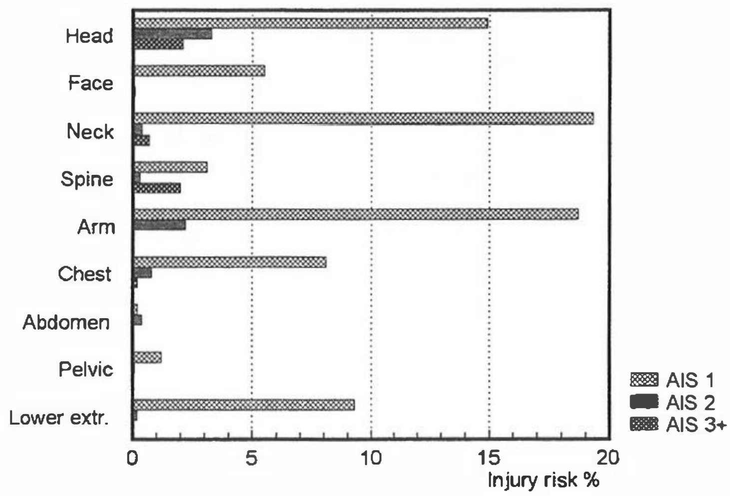


Figure. 2 - Injury risk for different body parts and injury levels. Note; the figure show MAIS per body part.

RESULTS FROM NASS DATA

For the variables describing the rollover configuration, the results show that in almost 60% of all rollovers the car has turned the equivalent of one turn or less, (≤ 4 quarter turns). The distribution of different rollover initiation types clearly shows that “trip-over” is the most dominating type of rollover with more than 50% of the cases. A “trip-over” is a rollover where the vehicle's lateral motion is resisted by an opposing force; inducing roll moment. The location of the rollover is, in more than 80% of cases beside the road or between the two roadways on a highway. The variable “rollover initiation object contacted” indicates that almost 50% of the cars hit the ground at the very beginning of the rollover. Other objects contacted, all with a frequency of less than 10%, were kerbstones, ditches, poles, trees, and other vehicles.

The injuries to the occupants are, in about 18% of the cases, MAIS 3+ injuries; mostly to the head, chest and spine. 15% are MAIS 2 injuries, dominated by injuries to the upper extremities, head, spine and lower extremities. Over 50% are MAIS 1 injuries. The most frequently injured body parts, receiving minor injuries, are upper extremities, face and lower extremities. 15% of the rollover occupants were uninjured. For the distribution of body parts in each injury severity group, see figure 3.

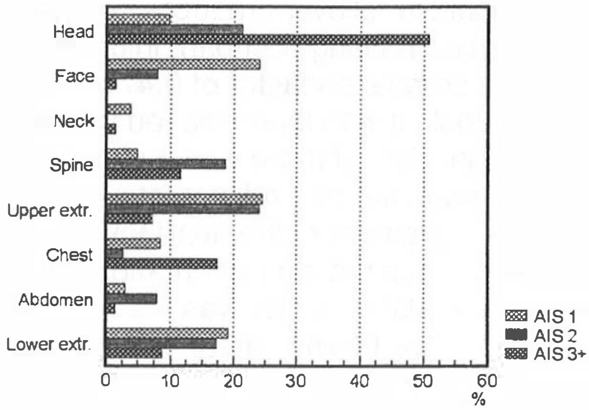


Figure 3. Distribution of body parts in the three different injury severity groups. Note that all injuries are included.

DISCUSSION

The number of MAIS 1, MAIS 2 and MAIS 3+ injuries in the in-depth study is in between those found in the STO and NASS subsets. In the NASS and STO data, as well as in the in-depth subset, the head and upper extremities are the most frequently injured body parts at AIS 2 level. The head is the most frequently injured body part for severe and fatal injuries (AIS3+). The in-depth study shows the same frequency for spine and head injuries in the severe to fatal injury category. Spine injuries are frequent, even in the STO subset. The most prominent difference between the three data subsets is the high amount of chest injuries (AIS3+) in NASS. This could be because the cars in the NASS data are of several different model types and thus contain different safety systems as compared to the Volvo database. Otherwise, the in-depth study cases seem to be a relevant and representative subset with respect to injury outcome.

The in-depth subset shows more extensive car deformations than in the statistical subsets. 90% of the cases in the in-depth subset have a maximum roof deformation of 25 cm or less, and for the STO study it is 20 cm or less. This could be because the in-depth studies usually contain cars of special interest, such as cars with deep deformation, unusual impact zones or injuries, or spectacular environments.

Comparing the in-depth study with the NASS data the number of turns shows similarities: in both cases about 60% of the rollovers are of one turn or less. Also regarding the site of rollover, the two data sets show similarities: e.g. 50% of the cases took place on the roadside. One difference between the two samples is regarding direction of rollover initiation. In the NASS data 50% had lateral motion compared to 35% of the in-depth cases.

Even if the rollover initiation and the deformation depth show some differences when compared to the two statistical analyses in STO and NASS, the in-depth study is considered to be a representative subset of rollovers.

Contrary to several other studies, the finding in this study is that car deformation is not correlated to injury severity. It is possible that the amount of in-depth knowledge available, which thus provides a true picture of the situation, tells us that the injury mechanisms in rollover are more complex than just the amount of car deformation. When correlating occupant injury to car deformation at the site of the occupant, a correlation factor of 0.47 was obtained. However when taking a closer look, it was found biased by the two occupants with fatal injuries due to ejection. Even if there was a certain amount of deformation at the position of the occupant, the ground impact was a result of the motion of the car causing a lateral movement of the head towards the ground. The direct injury-causing factor was not the car deformation. When these two occupants were excluded the correlation factor was 0.29.

When categorising the rollover situations the findings are that the AIS2-AIS6 injuries were mostly induced in rollovers with more complex kinematics, as in “high roll”, “side gliding” and “high fall”.

Despite efforts to correlate several different variables prior to or during rollover, no variables with good correlation to injury outcome could be found. In this area there is a need for a deeper understanding and evaluation of rollover accidents. It could also be that rollover accidents are very complex and very varied, and accordingly there is nothing such as a rollover severity measure.

The severe injury producing mechanisms of partial head ejection impacting the ground during rollover can be reduced by introducing design measures to retain the head inside the car. Suggestions for such measures include - in addition to improved side window and door integrity, roof framing and improved restraint design - systems such as the Inflatable Curtain (Öhlund et al, 1998). The Inflatable Curtain, which is activated in a side impact, will prevent the head from moving outside the compartment, and will also offer energy absorption as well as better impact surface.

FMVSS216 is a very restricted test method, describing a specific impact location. None of the in-depth cases resulted in car deformation identical to FMVSS216. When applying the same test method, but with different angles and impact locations, several real life car deformations could be reproduced. Even when considering this modified test method, only 11 of 21 cases could be described by an existing rollover test method. Obviously, there is a great need for further test method development in order to evaluate all real life situations. Especially the identified M, R, and S modes, not found to be covered by existing rollover test methods.

Also, when reconstructing rollover cases, a more human-like dummy would be needed. The HIII and other available dummies are too stiff.

CONCLUSIONS

Based on the 21 in-depth rollover cases, different rollover situations as well as five different roof deformation modes were defined.

Based on the shape of the roof deformation, only half of the cases analysed had a shape similar to that produced by published rollover test methods. Obviously, there is a need for further test method development in order to evaluate most of the real life situations. Especially the M, R, and S modes were not found to be covered by existing rollover test methods.

Four major injury-producing mechanisms were identified:
a) minor impact (minor body load)
b) impact with body load
c) friction impact
d) non-impact

The most common mechanism was minor impact; causing most minor injuries. The head impacting the rough-surfaced ground produced the most severe injuries.

No good correlation was found when combining injury outcome to several variables prior to or during impact (e.g. initial velocity, numbers of turns, rollover surface). Hence no single rollover severity measure could be defined. When grouped into the five different rollover situations it was found that a high-energy roll usually with a complex rollover pattern, results in more severe injury outcome.

In this material it was quite clear that amount of car deformation as a single parameter is not a measure of rollover severity.

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Case	velocity prior to impact (km/h)	Initiation of rollover	axis of rotation	number of turns	rollover surface	deformation mode	test method	rollover situation	occupant position	deformation at position	occupant injuries	contact area	injury producing mechanism
A	50	ramp up	x and z	1(x), 1/4(z)	5	T	I, II, IV	high roll	driver	3	head AIS 1	roof	b
											arm AIS 1	windshield	a
B	70	lateral acc	x	3/4	3	T	I, III, IV	low roll	driver	2	uninjured		
									front pass	0	uninjured		
D	80	ramp up	x and z	1,5(x), 1/4(z)	4	T	II, IV	high roll side gliding	driver	0	uninjured		
									front pass	5	head AIS 6	ground	c
											face AIS 3	ground	c
E	50	ramp up	x and z	1,5(x), 1/2(z)	1	T	I, IV	low roll	driver	2	head AIS 1	side window	a
											arm AIS 1	flying glas	a
F	90	ramp down	x	1	1	T	IV	high fall	driver, no belt				
									front pass	1	head AIS 1		b
											spine AIS 3	roof	b
											spine AIS 3	seat	b
											chest AIS 2	belt	d
									rear left	1	uninjured		
									rear right	3	head AIS 6	ground	c
											face AIS 3	ground	c
G	60	lateral acc	x	1	3	T, S	III, IV	high roll	driver	5	head AIS 1	windshield	a
									front pass	0	uninjured		
									rear left	3	uninjured		
									rear right	0	spine AIS 1	armrest	a
H	90	ramp up	y and z	1/2(y), 1/4(z)	5	T, S	IV, V	hihg roll	driver	5	face AIS 1	windshield	a
											arm AIS 2	interior	a
											chest AIS 1	belt	d
									front pass, no belt				
									rear left, no belt				
									rear right, no belt				
I	130	lateral acc	x and z	2,5(x), 1/2(z)	1	T, S	I, IV	low roll	driver	1	uninjured		
J	high	collision	x and z	>2(x), 1/2(z)	2	M	V	low roll, local object	driver	2	face AIS 1	roof	a
									front pass, no belt				
									rear left, no belt				
									rear right, no belt				
K	70	ramp up	x	1/2	4	M	V	low roll, local object	driver	1	neck AIS 1		d
L	60	ramp up	x and z	1/2(x), 1/4(z)	4	M	V	low roll, local object	driver	3	head AIS 2	roof	b
											head AIS 2	roof	a
											head AIS 1	roof	a
											neck AIS 1		d
											face AIS 1		a
											arm AIS 1		a
											leg AIS 1	instrument panel	b
									front pass	3	neck AIS 1		d
											face AIS 1		a
											leg AIS 1		a
											leg AIS 1		a
M	130	collision	x	3	2	M	V	low roll, local object	driver	3	AIS 1		a
									front pass	3	AIS 1		a
									rear left, no belt				
									rear right, no belt				
N	160	collision	x	1,25	1	M	V	low roll, local object	driver	1	arm AIS 1		a
											neck AIS 1		d
O	50	collision	x, y, z	1(x), 1/4(y), 1/2(z)	4	S, T	IV, V	low roll	driver	1	head AIS 1	glasses / airbag	a
											leg AIS 1	steering wheel	a

Case	velocity prior to impact (km/h)	Initiation of rollover	axis of rotation	number of turns	rollover surface	deformation mode	test method	rollover situation	occupant position	deformation at position	occupant injuries	contact area	injury producing mechanism
P	80	collision	z	1/2	3	R	V	high roll	driver	2	uninjured		
									front pass	2	head AIS 1	windshield	a
											leg AIS 1	instrument panel	a
									rear left	1	head AIS 1	c-pillar, glas	a
									rear right	1	head AIS 1	roof, glas	b
											chest AIS 1		d
R	60	collision	z	1,5	3	R	V	high roll	driver	0	head AIS 1		a
											arm AIS 2		b
											spine AIS 3		b
S	70	ramp up	x	1/2	3	O	II	no roof deformation	driver	0	uninjured		
									front pass	0	uninjured		
									rear right	0	head AIS 1		a
											face AIS 1	belt	d
T	70	lateral acc	x and z	1/2(x), 1/2(z)	4	O	V	no roof deformation	driver	0	head AIS 1	side window	a
U	90	collision	x and z	1(x), 1/4(z)	3	U	V	U	driver	U	uninjured		
									front pass	U	U		
V	70	lateral acc	x and z	>2(x), 1/2(z)	2	S	V	lowroll	driver	1	uninjured		
									front pass	1	leg AIS 1	glove box	a
									rear left	1	head AIS 1	front seat	a
									rear right	1	face AIS 1	c-pillar	a
											face AIS 1	side window	
X	100	lateral acc	x and z	1(x), 1/2(z)	2	S	V	high roll	driver	4	head AIS 2	windshield, roof	b
											head AIS 1	windshield	a
											arm AIS 2		b
											arm AIS 2		a
									rear right, no belt				

Variables	Variable values	Grading
Initiation of rollover	ramp down	1
	ramp up	2
	lateral acc	3
	collision	4
Axis of rotation	x - longitudinal axis	
	y - lateral axis	
	z - vertical axis	
Rollover surface	low friction	1
	..	2
	..	3
	..	4
	high friction	5
Test method	I - SAE J857	
	II - Screw-rollover	
	III - FMVSS 208	
	IV - FMVSS 216	
	V- none existing	
Deformation	0 - 5 cm	1
	6-10 cm	2
	11 - 15 cm	3
	16 - 20 cm	4
	21 - 25 cm	5
	26 - 30 cm	6

Correlation matrix

Correlations between potential severity measures and injured body parts

	MAIS	deformation	surface	initiation	number of turns	initial velocity	head	face	neck	chest	spine	arm
MAIS	1,00	0,47	-0,08	-0,36	-0,01	0,11						
deformation		1,00					0,47	0,47	0,10	0,08	-0,12	0,45
surface			1,00				-0,04	0,07	0,14	-0,08	-0,26	0,01
initiation				1,00			-0,27	-0,43	-0,08	-0,23	-0,30	-0,06
number of turns					1,00		-0,04	-0,03	-0,20	-0,18	-0,04	-0,13
initial velocity						1,00	0,03	0,05	0,20	0,16	0,07	0,24
head							1,00					
face								1,00				
neck									1,00			
chest										1,00		
spine											1,00	
arm												1,00